



## Recent Work in Archaeological Geophysics

The Geological Society  
Burlington House, Piccadilly, London W1J 0BG  
Tuesday 6<sup>th</sup> December 2022

### Programme

#### Lecture Programme:

- 0915-1000      **Registration and Coffee**
- 1000-1005      **Introduction**
- 1005-1020      *Integrating Geophysical and Remote Sensing Data for the Modelling of Geoarchaeological Resources in Alluvial Environments.* N Crabb, C Carey, A Howard and R Jackson
- 1025-1040      *Naught but Tradition Remains? Multi-Instrument Geophysics and the Recovery of the Landscape of Grand-Pre.* J Fowler
- 1045-1100      *Geophysics Has Its Day in Court: The Verdict on Rewilding Surveys at Court Green Manorial Settlement, Bere Regis.* P Cheetham and D Stewart
- 1105-1120      *Early Results from Large-Scale Multi-Method Geophysical Surveys at the Battlefield of Waterloo, Belgium.* D Williams, P De Smedt, K Welham and S Eve.
- 1125-1155      **Tea/Coffee break**
- 1155-1210      *Exploring Interoperability of Archaeological and Agricultural Geophysics. The Case of East Heslerton.* J Verhegge, R Opitz, E Baldwin, D Powlesland, S Campana, M Vieri, V Mayoral Herrera, V Robinson, R Fry and P De Smedt
- 1215-1230      *Municipal Garden Waste Compost: Its Effect on Magnetometry Results.* R Ainslie
- 1235-1250      *Evaluating Methodologies for Magnetometer Surveys in Wooded Areas.* A Schmidt and W Weber
- 1255-1300      **Morning closing remarks**

- 1300-1430      **Lunch (Lower Library) – all delegates**  
**NSGG AGM (Lecture Theatre) – all welcome**
- 1430-1445      *Large Scale Geophysical Investigations of the Medieval Manor of Austrått in Mid-Norway – Combining Metal Detecting, GPR and Magnetometer Surveys.* A Stamnes
- 1450-1505      *After the Biblical Flood: Magnetometer Prospecting at Fara (Iraq) to Assess the Excavations at Ancient Šuruppak from 120 Years Ago.* S Hahn, J Fassbinder, A Otto and B Einwag
- 1510-1525      *3D GPR Survey in the Recognition of Relics of Pre-War Buildings for the Reconstruction of the Saxon Palace in Warsaw (Poland).* M Pisz, R Mieszkowski, S Kowalczyk and E Krogulec
- 1530-1545      *Tracing Roman Grave Monuments in Ruffenhofen (Bavaria, Germany).* R Linck, A Stele and D Lenz
- 1550-1620      **Tea/Coffee break**
- 1620-1635      *GPR at Gorhambury: Surveys by the Community Archaeology Geophysics Group at the Roman City of Verulamium.* K Lockyear
- 1640-1655      *Old and New Frontiers: Ground Penetrating Radar Surveys at the Roman Fort of Trimontium.* K Armstrong, J Lawton and S Ovenden
- 1700-1715      *Reminiscences on 30 Years of Magnetic Surveying (Mostly) in the UK.* J Lyall
- 1720-1730      **Conclusion**
- 1735-1900      **ISAP AGM (Lecture Theatre)**

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

*Touching the Past: Tactile Models of Geophysical Images for Improving User Access to Archaeological Data Displays.* A Booth, B Thomas, R Holt, S Sanchez, L Makin, S Ok, T Roberts and N Linford

*Hydrological Assessment of Quarrendon Leas Elizabethan Water Gardens with a Portable Time Domain Electromagnetic System.* M Guy and V Guy

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



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# LECTURE ABSTRACTS

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## INTEGRATING GEOPHYSICAL AND REMOTE SENSING DATA FOR THE MODELLING OF GEOARCHAEOLOGICAL RESOURCES IN ALLUVIAL ENVIRONMENTS.

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Shallow magnetic gradiometer surveys are now regularly deployed at a landscape scale, covering 100s and sometimes 1000s of hectares, particularly prior to infrastructure projects. The consideration of the geological, geomorphological, and topographical context of these large areas is fundamental, and without this context it is not possible to completely interpret these results. Moreover, in landscapes where archaeological resources do not lie immediately below the modern ground surface (i.e. a soil profile above bedrock), but are buried below accumulated sediments (e.g. alluvial, colluvial, aeolian, coastal, estuarine, and lacustrine deposits), most conventional (shallow) geophysical techniques will be largely ineffective, but this limitation is not always explicitly acknowledged. However, through integration with remote sensing techniques, other (deeper) methods of geophysical survey, and the construction of geoarchaeological deposit models, it is possible to map the likely distribution of buried deposits of archaeological interest (Carey et al., 2018). This allows for areas of greater and lesser archaeological potential to be established, which, in turn, enables the context of archaeological remains to be better understood and subsequent investigations to be more focused (Historic England, 2020).

This paper will demonstrate how geophysical survey and remote sensing techniques can be integrated within the framework of geoarchaeological deposit modelling to provide an improved understanding of complex depositional zones, where standard shallow archaeological prospection methods are ineffective (Weston, 2001). It focuses on alluvial environments, as they frequently contain rich and well-preserved archaeological and palaeoecological records, which are increasingly threatened by development, agriculture, and climate change (Howard et al., 2015). This includes a detailed case study centred on the Lower Lugg Valley in Herefordshire, where previous research has recorded a complex depositional history, with closely related human-environmental interactions, and widespread archaeological activity (Dinn and Roseff, 1992; Dorling, 2007; Jackson and Miller, 2011). The results have implications for applications of these methods in other complex depositional zones and it is argued that such an approach should be adopted more widely.

### Identifying archaeological potential in alluvial environments

Temperate river floodplains contain an assemblage of alluvial landforms that provide a record of the evolution of the river system (Brown, 1997). As the likely preservation

of archaeological resources varies according to the distribution and type of these landforms, understanding their morphology, and sedimentary sequences is imperative for predicting archaeological potential. For example, the presence of palaeochannels, gravel islands, levees, bars and other bedforms exert a significant influence on past societal choices and mapping and understanding these landform assemblages can, therefore, offer significant insights into the distribution of archaeological resources (Challis and Howard, 2006, 2003).

Geoarchaeological deposit models provide a visual representation of the spatial and stratigraphic relationships between subsurface sediments, archaeological features and palaeoenvironmental remains (Carey et al., 2018). Whilst they vary in their form and presentation, they generally aim to improve the understanding of depositional environments and make predictions regarding archaeological potential (Brown et al., 2005; Carey et al., 2017; Howard et al., 2008). They are conventionally constructed by combining pre-existing archaeological and Historic Environment Records, geological mapping, and intrusive geotechnical data. However, they can also incorporate proxy measurements of the subsurface provided by remote sensing or deeper geophysical survey methods.

Numerous projects have used airborne lidar for topographic modelling of landforms of variable archaeological or palaeoenvironmental potential (Bunning and Farr-Cox, 2006; Mozzi et al., 2018; Ninfo et al., 2011; Passmore and Waddington, 2009; Stein et al., 2017).

However, any resources that are not expressed topographically, due to significant alluvial deposition or agricultural activity, will not be identifiable. Whilst multispectral data is also limited to surface measurements (e.g. spectral reflectance relating to soil moisture or plant health), it can act as a proxy indicator of buried features, landforms and sub-surface sediment architectures (Crabb et al., 2022). Moreover, with reductions in costs and recent technological advancements, including the improving spatial resolution of satellite systems and the advent of lightweight UAS mounted instruments, these datasets are increasingly accessible for geoarchaeological research.

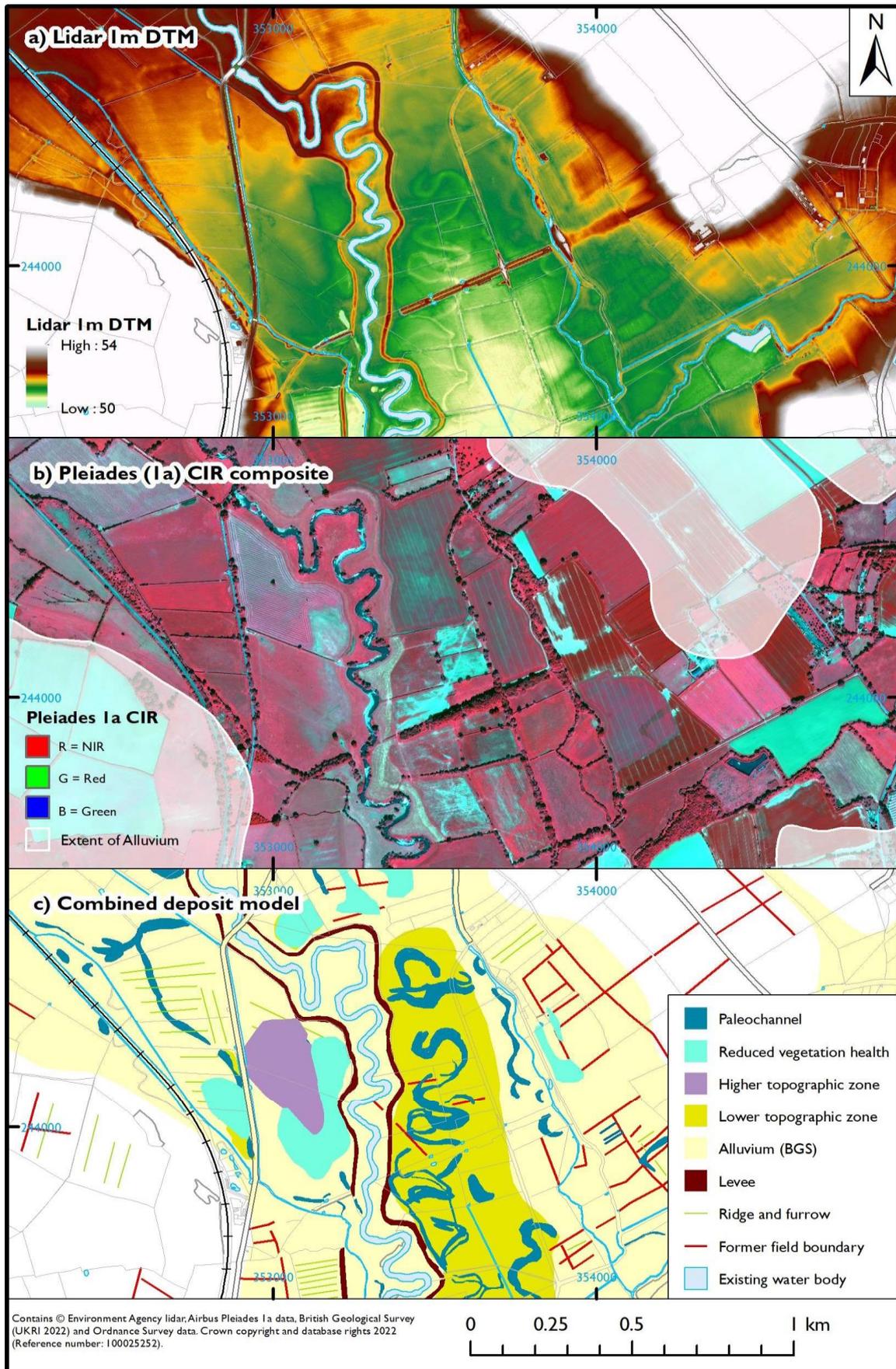


Figure 1: Alluvial landforms defined by remote sensing Techniques to create a deposit model.

## The Lower Lugg Valley, Herefordshire (UK)

In the Lower Lugg Valley, lidar was used to highlight the central, vertically accreting portion of the alluvial corridor, together with a series of more discrete alluvial landforms, such as palaeochannels and gravel topographic high points (Figure 1a). These landforms were also identifiable within high-resolution satellite multispectral imagery, but in addition, larger scale landforms (e.g. a probable gravel island) were more apparent as variations in vegetation health (Figure 1b).

Collectively, these datasets were used in conjunction with a small number of boreholes (Figure 2d) to produce a simple deposit model (Figure 1c). This enabled predictions to be made regarding the distribution of archaeological resources, where lower-lying (wetter) areas and palaeochannels were considered more likely to contain paleoenvironmental resources, whereas higher (drier) zones, relating to upstanding gravel terraces or islands, are unlikely contain such remains, but were more attractive for a range of past human activities.

An Electromagnetic (EM) induction survey was carried out to test the deposit model constructed from remote sensing and borehole data, and to better characterise the nature and distribution of subsurface deposits and alluvial landforms (Figure 2a). The EM survey confirmed the presence of a gravel island identifiable in both the lidar and multispectral data, which had thinner deposits of alluvium on its surface defining a higher archaeological potential (Figure 2d). Due to the higher and drier position of this landform within the floodplain, a gradiometer survey was also undertaken to identify possible archaeological features (Figure 2b and c). This defined some tentative anomalies, predominantly concentrated upon the topographic (gravel) high point, helping to confirm the predictions of the deposit model. However, even though the targeted gradiometer survey was undertaken in an area of shallower alluvium, the alluvial deposit sequences were still predominantly >1 m in depth and consequently, are likely to have been too deep for the gradiometer to identify features at the Pleistocene/Holocene interface at the base of the sequences. Despite this, these results illustrate how appropriate geophysical survey and remote sensing techniques can be integrated to provide a better representation of the nature and distribution of archaeological resources within alluvial landscapes.

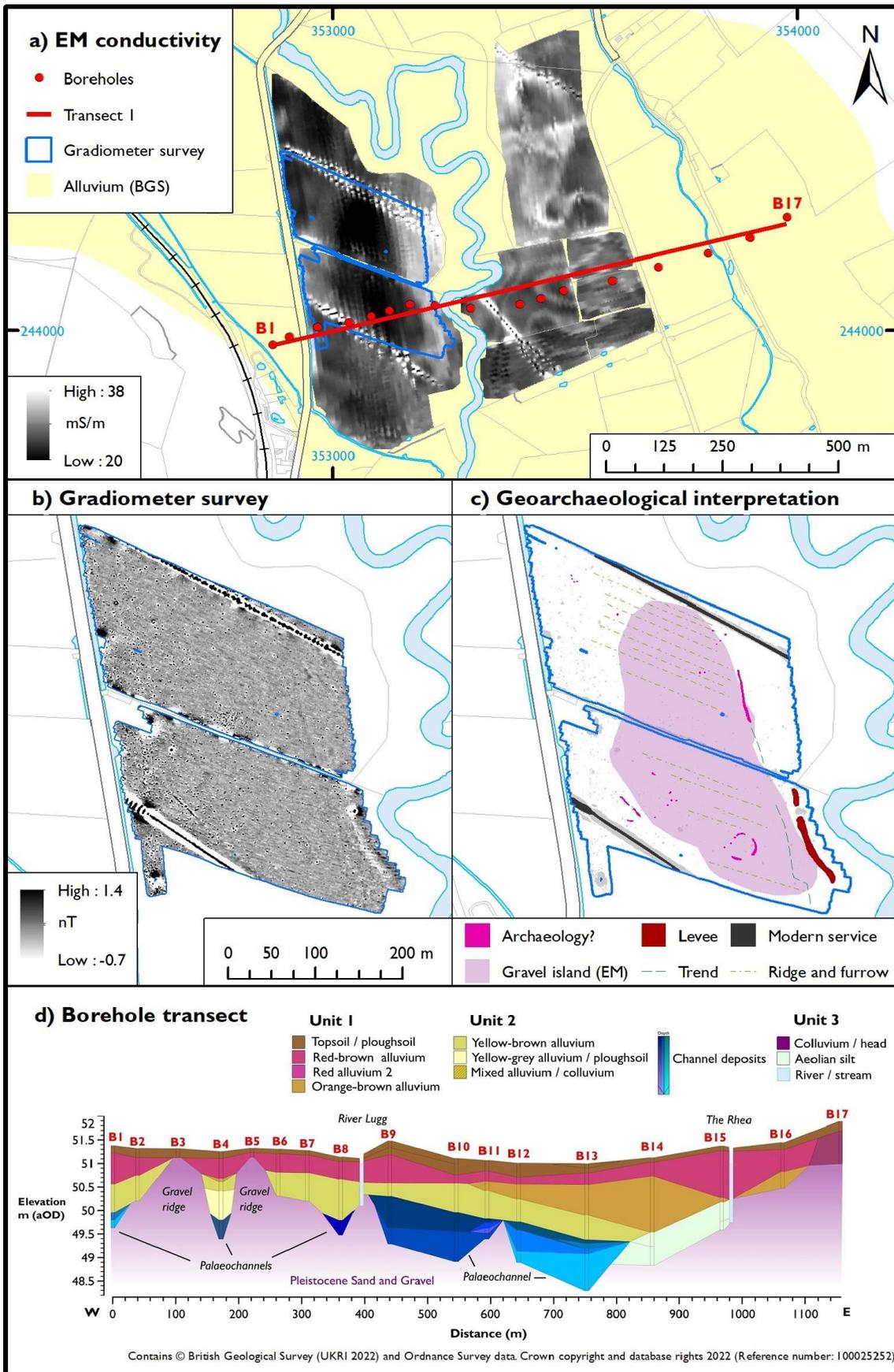


Figure 2: Alluvial landforms and archaeological features characterised through geophysical survey and borehole transect.

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## NAUGHT BUT TRADITION REMAINS? MULTI-INSTRUMENT GEOPHYSICS AND THE RECOVERY OF THE LANDSCAPE OF GRAND-PRÉ

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Grand-Pré was one of the most prosperous French Acadian settlements in Northeast North America before it was occupied and destroyed by New England soldiers in 1755, its hundreds of residents loaded onto deportation ships and sent into exile to the American colonies. The global reach of their subsequent wanderings became legendary: France, England, the Caribbean, even the Falkland Islands. Many Acadian refugees relocated to Louisiana, where they became known as Cajuns.

Their devastated homeland, later transformed by Protestant immigrants into a New England township, eventually became a place of solemn memorialization and pilgrimage. Grand-Pré National Historic Site of Canada and The Landscape of Grand Pré World Heritage Site today commemorate Acadian survival and celebrate the ingenuity of colonial-era farmers whose dykes and drains claimed the *Great Meadow* (Figure 1) from the world's highest tides (Bleakney 2004).

The American poet Henry Wadsworth Longfellow used the 1755 Deportation of the Acadians as inspiration for his epic poem *Evangeline: A Tale of Acadie* (Longfellow 1847). His vivid reimagining of the Acadian story energized modern Acadian nationalism and stimulated heritage development (Griffiths 1982; Fowler and Noël 2017). It also misrepresented the Acadians and their history.

“Naught but tradition remains of the beautiful village of Grand-Pré,” Longfellow sighed. But archaeology is proving him wrong.



*Figure 1: The Great Meadow (Grand-Pré) as viewed from the north. Photo by Ian McKay.*

For the past 20 years, our teams have combined a range of aerial and terrestrial remote sensing techniques with targeted archaeological excavations to recover the tangible remains of Acadian Grand-Pré. Most of its inhabitants were not literate and few contemporary plans or descriptions of the community survive, so the picture emerging from our research is new. Our research also offers a valuable feedback loop in which different instruments and survey methods have been compared and ground-truthed through excavation.

This presentation briefly situates Acadian Grand-Pré in space and time before outlining our multi-instrument approach and some of its main results to date.

Techniques include electromagnetic (EM) conductivity and magnetic susceptibility with the EM38 series of instruments by Geonics, ground-penetrating radar, aerial photography, and aerial LiDAR (Figure 2).



Figure 2: 1760s cadastral map of Grand-Pré georeferenced and applied to 2019 LiDAR-derived bare earth digital elevation model. Data courtesy of Province of Nova Scotia.

Our results once again demonstrate the value of multi-instrument surveys combined with historical research and excavation. Traditional aerial photography, drone-based digital photogrammetry, and aerial LiDAR identify areas of high archaeological potential. Extensive EM surveys follow. Magnetic susceptibility is particularly instructive because much of the settlement appears to have been burned in 1755 or shortly thereafter. With the clusters of domestic sites identified by these methods, GPR yields more thorough, 3D mapping, and dating evidence is obtained through excavation. Much of the work of mapping this storied community is conducted as part undergraduate coursework at Saint Mary's University.

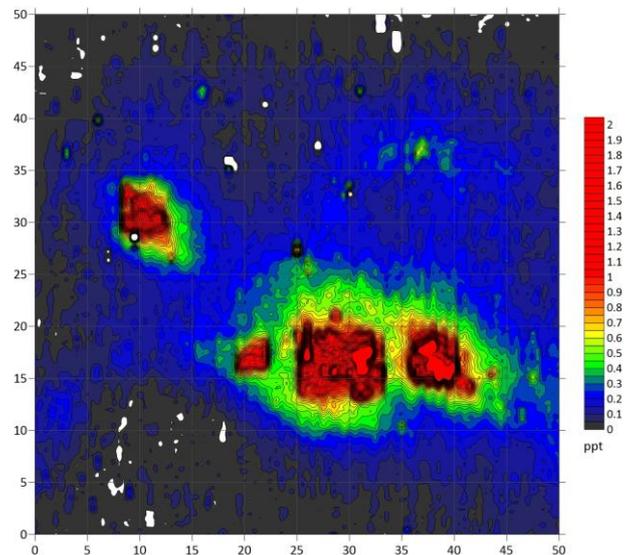


Figure3: In-Phase results from a EM38B with 50cm interline spacing and 10 samples per second

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## GEOPHYSICS HAS ITS DAY IN COURT: THE VERDICT ON REWILDING SURVEYS AT COURT GREEN MANORIAL SETTLEMENT, BERE REGIS

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**Keywords:** Rewilding, magnetometry, earth resistance, ground penetrating radar.

In its aims of restoring natural processes and increasing biodiversity, the rewilding movement is principally ‘natural environment’ driven, but in addition often aims to promote and enable community access. Land acquired by Dorset Wildlife Trust along the northern banks of the Bere Stream to the east of Bere Regis provides a good case study of the process of ‘rewilding’ with respect to our knowledge and understanding of the archaeological record of an historic landscape exploited and modified by man for over 7000 years. Entitled *Wild Woodbury*, the project is named after the Woodbury univallate hillfort that overlooks the area.

Rewilding takes many forms, with the project undertaken at Court Farm being focussed on low-input farming where the term ‘wilder farming’ would be considered more appropriate. The project will involve some areas of natural scrub and woodland regeneration and the removal of modern drainage to re-wet parts of the landscape (Farrington 2022). Whilst taking this area out of intense agricultural production protects the archaeology from the ravages of the plough, allowing nature to take its course will mean that in the future some areas may become less accessible for undertaking effective conventional geophysical survey. There are also plans to repurpose redundant agricultural buildings, create wildflower meadows and create a community food forest. Some project activities encroach on the scheduled area of the manorial settlement of Court Green and so appropriate scheduled monument consent is required. Geophysical survey had already been successfully applied to one area of the Court Farm manorial settlement and so it was logical to extend this work to cover the whole of the scheduled area, which has now been completed (Cheetham 2022). Survey involved the use of magnetometry, earth resistance and ground penetrating radar to investigate the archaeological potential and guide the management of the scheduled area. Despite the inherent limitations of geophysical survey with respect to the ephemeral nature of some medieval archaeology, perhaps fortuitously, the geophysical survey revealed that parts of the site are covered in relatively modern overburdens. These mask, but therefore protect, some of the area that may be affected by the changes in land use.

Next to be considered are the unscheduled areas of *Wild Woodbury*. Archaeological survey and excavation on adjacent areas of the south-west facing slopes of the Bere Stream valley revealed them to be rich in archaeological activity dating from the Mesolithic period onwards (Context One 2017), suggesting there were many sites to be discovered in the unscheduled parts the *Wild Woodbury* rewilding area. Local historian John Pitfield had also undertaken surface collection over parts of the rewilding area, and Dorset Wildlife Trust staff, when alerted to the signs of settlement and activity, reported several potential archaeological sites. A brief walk-over of part

of the rewilding area by the first author revealed the tell-tale signs of flint debitage and pottery from prehistoric sites, the burnt flint ‘pot boilers’ from Iron Age domestic sites, and areas of medieval and early post-medieval pottery together with a few sherds of Roman ceramics. In agreement with Dorset Wildlife Trust, it has been proposed that parts of the rewilding area are geophysically surveyed before they become less accessible. This will allow any archaeological sites identified to be managed appropriately within the rewilding project. The results so far confirm that a wide range archaeological sites exist, with work ongoing to complete the project. For example, in figure 1, below, a randomly surveyed area reveals a palimpsest of prehistoric and later magnetic anomalies/features located on a chalk spur overlooking the river.



Figure 1: This randomly selected area of magnetic survey reveals a palimpsest of ditches, pits, lynchets and quarry pits, demonstrating the archaeological potential of the Wild Woodbury rewilding area. Bartington 601-2, 0.25 x 1m survey intervals. Black positive, plotted -3 to +3 nT.

## Acknowledgements

The authors would like to thank Rob Farrington of the Dorset Wildlife Trust for commenting on the original draft.

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## EARLY RESULTS FROM LARGE-SCALE MULTI-METHOD GEOPHYSICAL SURVEYS AT THE BATTLEFIELD OF WATERLOO, BELGIUM

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This paper examines the initial results of large-scale geophysical surveys recently undertaken at the Battlefield of Waterloo in Belgium (**Figure 3**), where Napoleon Bonaparte was famously defeated in June of 1815 by a European coalition led by the Duke of Wellington and Prussian Marshal von Blücher. Archaeological research under the auspices of the British charitable organization *Waterloo Uncovered* have been ongoing at the site since 2015. Geophysical surveys were trialled with promising results at the inception of the project and have recently been scaled up to increasingly large areas of the protected battlefield landscape, which comprises a surface area of over 1000 hectares.

Over 100 hectares of this landscape have now been surveyed using fluxgate magnetometry (Sensys MXPDA) and multi-receiver frequency-domain electromagnetic induction (DualEM 21H – coil spacings of 0.5, 1 and 2m) (**Figure 4**, **Figure 5**). Magnetometry was undertaken using a five-sensor array with 50 cm sensor spacing and a 100 Hz sampling rate to allow for the identification of relatively small archaeological features (>1 m) and metal scatters (**Figure 6**). Coarser sampling was used for the EM surveys (2 m interline spacing at 8 Hz) to target broader pedological variability (in particular colluvial deposits based on electrical contrasts related to soil textural differences) (**Figure 7**) and larger archaeological features. Previous attempts at using ground-penetrating radar at the site have shown that signal attenuation is generally quite high, which is problematic in an environment that has experienced considerable colluvial accumulation resulting in buried archaeological deposits of interest at depths of up to 1m.

These methods were selected for their ability to provide complementary datasets on both magnetic and electric properties at a range of depths and to enable identification of a wide range of potential targets (e.g., hearths and other features related to bivouacs, scatters of metal ordnance, mass graves/cremation pyres, expedient defensive works, and other relevant landscape features such as field boundaries, ditches, structures, and paths).

A range of areas have been sampled, including the main ridge along which the Allied forces were deployed and where they bivouacked the night preceding the battle, areas around several farmhouses which played pivotal roles as expedient fortifications during the battle, and the hinterland of the village of Plancenoit which was the site of a crucial struggle between French and Prussian forces. We present initial results from these surveys, considering the potential advantages and shortcomings of the methods for identifying various targets related to the battle and its aftermath.

While geophysical surveys have been attempted at many battlefields in the past, we believe that this survey represents the largest of its kind ever undertaken at an early

modern battlefield. This has been enabled by mobile survey configurations, now well-established in archaeological prospection, which have shown their value in producing large-scale datasets for understanding vast archaeological landscapes. Battlefield sites have long been considered challenging for archaeological investigation due to the low-density ephemeral nature of the material evidence and their large spatial extent. The primary methodology employed in their investigation has traditionally been systematic survey with conventional metal detectors which, while effective, limits the potential range of targets that are detectable. We consider how large-scale surveys incorporating other geophysical approaches might enhance our understanding of these ephemeral archaeological landscapes.



*Figure 3: Map of the battle showing initial troop deployments, produced in 1816, with the protected battlefield area outlined in red. Wellington's Anglo-Allied army (shown in red) deployed along a ridge at the top of the map, with Napoleon's French army in the centre and south (in blue) and Blucher's Prussian forces (in green) approaching the village of Plancenoit in the southeastern corner.*



*Figure 4: Electromagnetic induction survey near the Lion Mound monument, Waterloo.*



*Figure 5: Magnetometer survey near Hougoumont Farm, Waterloo.*

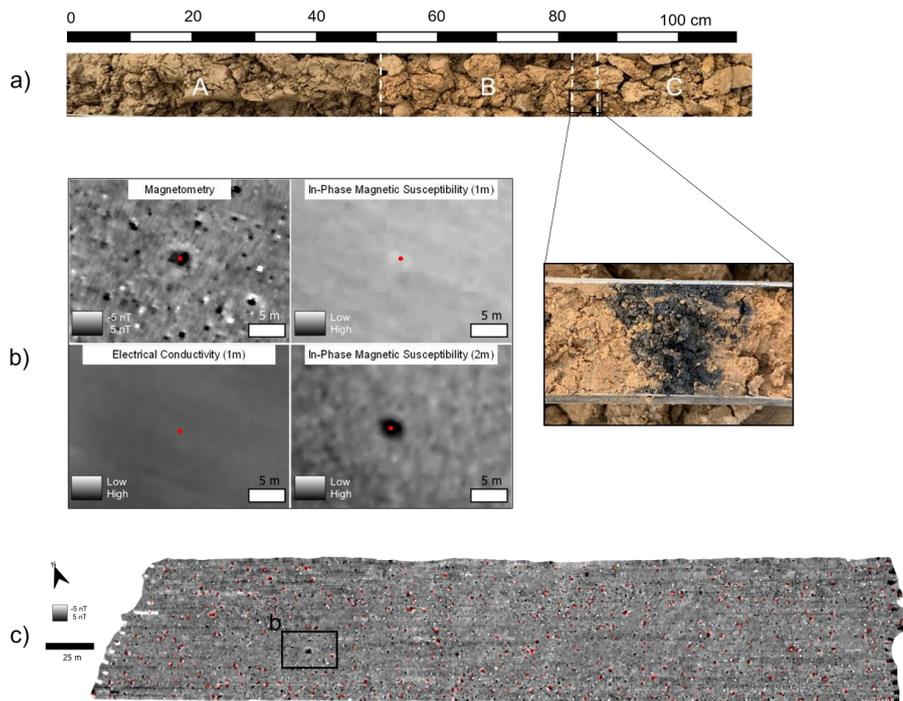


Figure 6: Example of subtle archaeological feature detected near the ridge that comprised Wellington's main defensive position, consisting of burnt soil lens and associated ferrous metal fragments beneath approximately 80 cm of colluvial overburden. Borehole shown in a); different geophysical contrasts of feature from FDEM and magnetometry surveys in b) along with borehole location indicated by red dot; and larger magnetometry dataset in c) showing inset area and dipole anomalies highlighted in red.

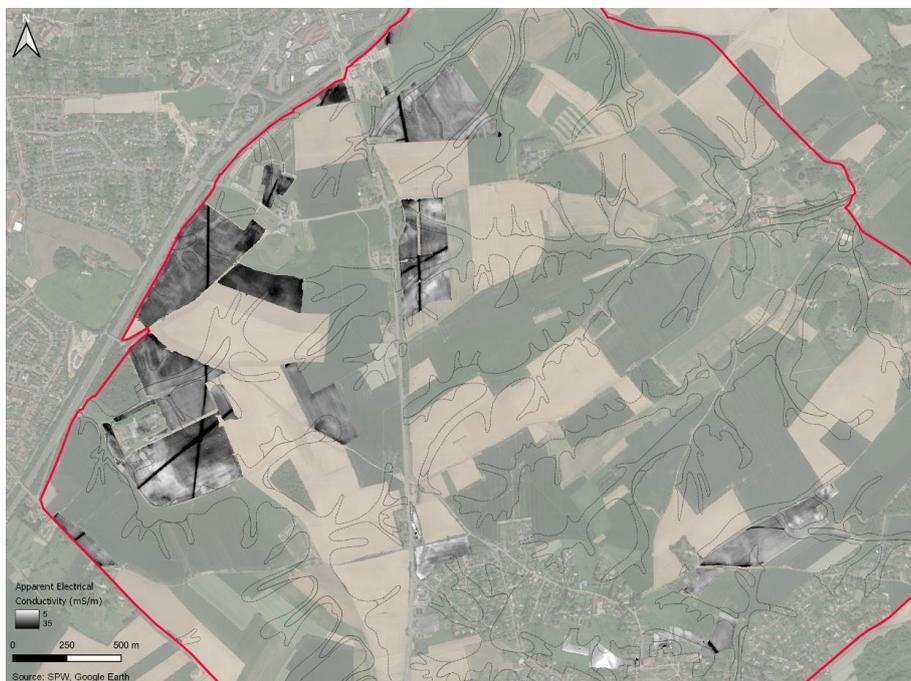


Figure 7: Overview of apparent electrical conductivity (1m horizontal coplanar coil pair) for entire surveyed area. Note especially the linear resistive zones correlating well with colluvial deposits (outlined in black, from mid-20th century soil surveys). The red outlined area is the protected battlefield zone as shown in full in Figure 3.

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## EXPLORING INTEROPERABILITY OF ARCHAEOLOGICAL AND AGRICULTURAL GEOPHYSICS. THE CASE OF EAST HESLERTON.

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### Introduction

Over the past decades, technological innovation has revolutionised archaeological prospection, by enabling large-area geophysical surveys (e.g. Powlesland, 2006), and farming practice, through proximal soil sensing (Adamchuk and Viscarra Rossel, 2011). Hereby, both disciplines have deployed similar methodologies and encountered comparable challenges. While mutual benefits have been identified (Webber et al., 2019), truly interoperable archaeological and agricultural survey, requiring common (meta)data standards and workflows, is still afar. The Interoperable Precision Agricultural and Archaeological Sensing Technologies Project (ipaast-czo) pursues this by integrating in-place systems, stakeholder- and user surveys, workshops and interdisciplinary case-studies. One case-study is East Heslerton, where Powlesland (2006) revealed an Iron age-Roman ladder settlement, Anglo-Saxon *Grubenhäuser*, and various fluvial features using magnetometer survey (MAG) (Fig.1-Right). Complementing gridded borehole survey mapped ploughsoil and sandy aeolian overburden thickness (Fig. 1-Left). To evaluate how archaeological prospection sensor data serve agricultural services, and vice versa, a multi method study focused on frequency domain electromagnetic (FDEM) induction and gamma ray survey.

### Methodology

While in precision agriculture FDEM sensors are often used for creating management zones primarily based on the outputted apparent electrical conductivity (ECa), the in-phase magnetic susceptibility (IP-MS) is often also of interest for archaeological prospection (e.g. De Smedt et al. 2022). Because of this common interest, FDEM was selected, despite differing field and processing practices in both applications. Data were collected with a Dualem 21HS instrument at 1.2 m between- line spacing, and processed following Hanssens et al. (2020) to produce ECa and IP-MS maps. These were then used to develop a stratified random sampling scheme (Minasny and McBratney, 2006) linking electromagnetic variations to standard physicochemical soil properties. For all samples texture composition, OM, CEC, CaCO<sub>3</sub>, pH\_KCl, P, K, Mg, Ca and C/N were quantified, alongside lab magnetic susceptibility (Bartington MS2B). Based on the ECa and IP-MS, agricultural management zones (AMZ) were defined using K-means

clustering.

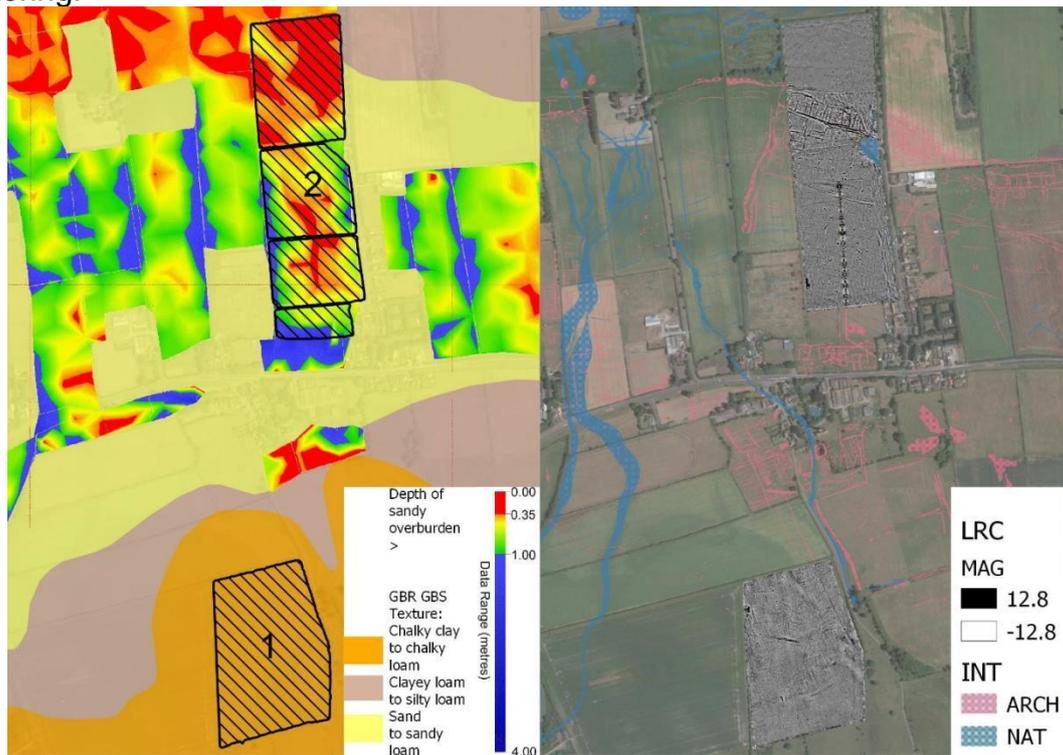


Figure 1: Left: Survey areas (dashed+numbered) and thickness of the aeolian sand deposits. Background: BGS Parent material-soil texture; Right: LRC MAG results and interpretations.

## Results and discussion

Grubenhäuser appear as discrete, strong magnetic enhancements (e.g. Fig.2-Center: MS\_4), both on the slopes and sandy valley floor. Linear enclosure ditches on the slopes (MS\_5) exhibit lower IP-MS than to the drainage dyke, trackway- and enclosure ditches of the ladder settlement (MS\_9). The latter exhibit increased ECa, indicating finer/organic infill (EC\_7).

In area 1, the ECa reveals the variable bedding lithology and fault lines of the chalky geology of the valley slopes (Left: EC\_1). Locally, these have been eroded by fluvial and/or slope processes resulting in a large dry valley with a low ECa (EC\_2), indicating a coarser texture. The IP-MS is lowest on top of a steep ridge between two valleys (MS\_1), representing a shallow/eroded topsoil. Downslope, increased IP-MS and ECa reveal where finer deposits have colluviated (MS\_2, EC\_3), while the dry valley also exhibits subtly increased IP-MS (MS\_3).

In the area 2, the valley floor has very low ECa in the south, indicating the presence of coarse, dry sands (EC\_4). The northern half is more conductive, suggesting finer and/or more waterlogged sediments (EC\_5). A paleochannel contributes the highest ECa indicating loamy/organic rich soil conditions (EC\_6). The large scale IP-MS seems to increase with a thicker sandy overburden (MS\_8) compared to e.g. MS\_6/MS\_7. The differing spatial variability with the ECa suggests that the sandy sediments consist of a more magnetic overburden and less magnetic underburden.

Alternatively, the magnetic enhancement results from human land use, since it is higher near the ladder settlement and current town.

Compared to MAG, FDEM results contribute new information layer about soil and geology, which is valuable both in reconstructing archaeological landscapes; guiding soil sampling and creating AMZ.

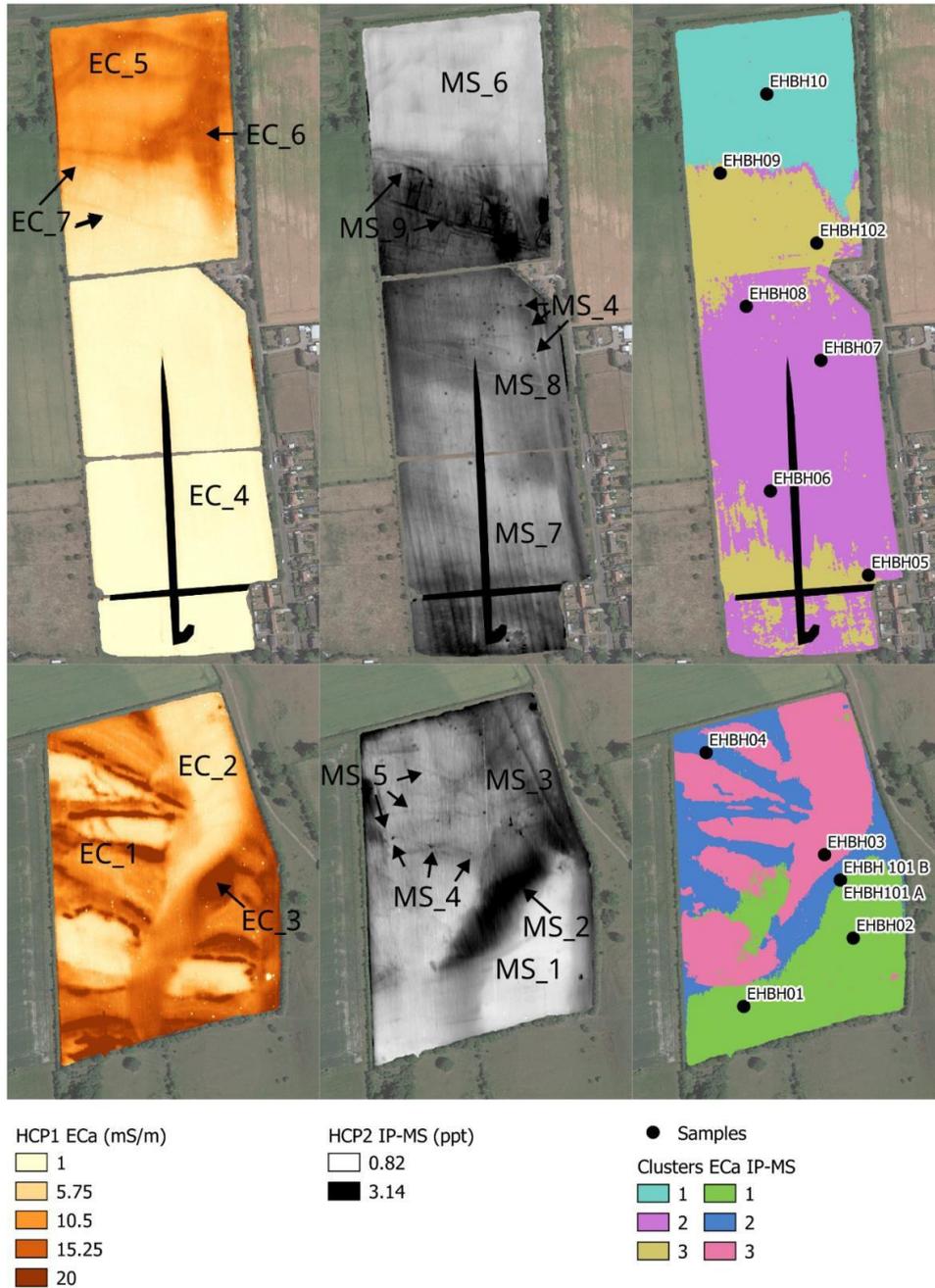


Figure 2: Left: ECa dataplot in 1 m HCP coil configuration; Centre: IP-MS dataplot in 2 m HCP coil configuration; Right: Sample locations and delineated management zones.

K-means clustering of the IP-MS and ECa classified each field in to three clusters, usable as AMZ (Fig.2-right). Texture analyses of the samples revealed textures from sand to clay-loam. A relatively good correlation ( $R= 0.71$ ,  $p=0.071$ ) was observed between low frequency MS and Phosphorous content (Fig. 3) within area 2, but was absent in area 1. The sample's mineralogy is under analysis to determine the origin, but this suggests IP-MS as phosphorous proxy.

## Conclusion

This project demonstrates how a single multi-use dataset can be collected by surveying at a high spatial resolution, employing appropriate calibrations, and integrating physiochemical soil analysis.

Importantly, precise drift removal enabled archaeological IP-MS interpretations and established IP-MS as a possible predictor of P content. Furthermore, soil/geological variability is mapped in ECa and IP-MS, making gridded augering or sampling superfluous for mapping these variations. Instead, these should be implemented in a targeted manner.

This highlights the potential practical benefits of a collaborative approach: sharing costs between stakeholders in agriculture, environment and archaeology could make acquiring higher resolution, better quality soils data practical for all.

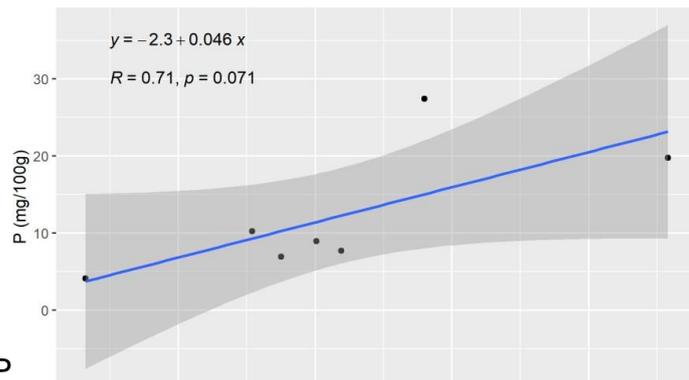


Figure 3: Linear regression plot between Low Frequency MS and Phosphorous content of the area 2 samples

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## MUNICIPAL GARDEN WASTE COMPOST: ITS EFFECT ON MAGNETOMETRY RESULTS

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Figure 1: Air photo of Andersey Island with Abingdon bridge.

### Summary

This compost appears to contain material which introduces a speckled appearance to magnetometry results. This may well lead to remains not being as clearly detectable by this method.

### Background

We have surveyed the same area near Abingdon several times as we live nearby. The area concerned is at 51 deg 40'N 1deg16'27"W, on a fairly level gravel terrace near the Thames.

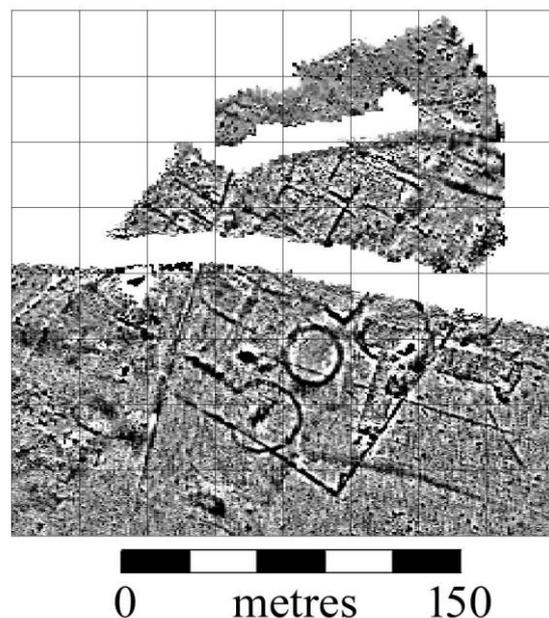
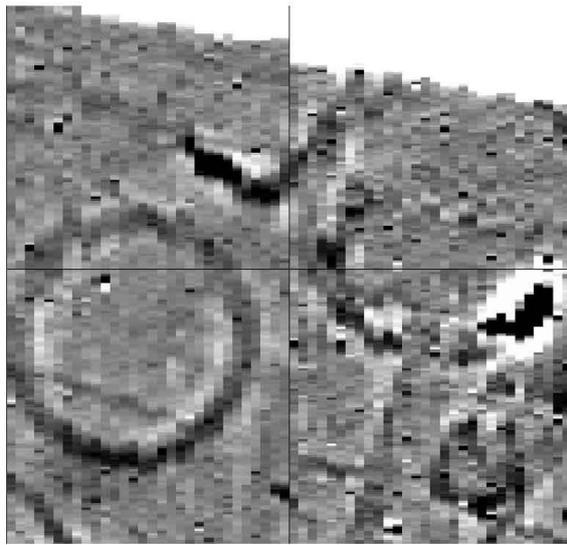


Figure 2: Part of the main survey area



2006



2021

Figure 3: Detail of 30 metre grids surveyed with a Bartington Grad 601/2 gradiometer.

### Results

We appear to have gone from 1 piece of, (presumably ferrous), speckle in the south westerly round barrow area in 2006, to 6 in 2018 and 16 in 2021. The farmer has advised that this area has had municipal green compost from the Local Authority depot at Sutton Courtenay used on it 3 times, at a rate of 10 tonnes per hectare each time. He has stopped using it as it contained too much plastic.

### Discussion

This study might enable a view to be taken on whether ferrous material should be removed before such compost is used, although this may carry little weight in the overall scheme of things. The alternative is to have fields surveyed before this material is deposited. Landfill sites are recorded for methane and heavy metal contamination aspects, so perhaps areas where municipal compost has been deposited should similarly be in the public record.

James Gerrard and others put an article into *Archaeological Prospection* <sup>(1)</sup> showing the masking effects of this substance and also giving detail of the amount of contamination it was permitted to contain. As this is a paywall journal it seems not to have had the circulation it deserves. Metal detectorists were also concerned and there was even an item on the BBC Countryfile TV series about it, but nothing appears to have been done to recognise and address the problem.

Why it matters. A high amount of this contaminant can conceal almost everything. As sometimes remains are identified by the location of pieces of iron in the ground, a random scatter of it can stop remains being identified.



Figure 4: Plastic litter from municipal compost

The amount of plastic in this compost is the thing which most people see and are concerned about. It may have been seen as a good idea to reduce landfill by taxing biodegradable waste at almost £100 per tonne compared to £3 a tonne for inert waste. In terms of gas production this is probably carbon dioxide in aerobic conditions and methane for anaerobic situations. This material may be best put in capped tips, where they can collect the methane and use it to generate electricity, and the taxation adjusted accordingly.

This compost may belong to the category of good ideas gone bad such as asbestos insulation, high alumina cement, pitch fibre pipes etc.

### **Acknowledgements**

We would like to thank the farmers and landowners for access and Sally Ainslie and Chris Oatley for surveying and Dr's. Armin Schmidt and James Gerrard for their advice.

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## EVALUATING METHODOLOGIES FOR MAGNETOMETER SURVEYS IN WOODED AREAS

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The Iron Age banked enclosure in the wooded area of the Messbüsch of Eisenach, Rhineland-Palatinate, Germany, is clearly visible in the LiDAR data, with a size of 40 m × 37 m inside its banks (Figure 1). Although overgrown with trees and shrubs the topographic changes are still evident on the ground. Inside other Iron Age enclosures in Germany and the UK magnetometer surveys had previously identify various internal features (Becker 1985; Marshall 1999; Marshall 2001; Berghausen 2014) and a magnetometer survey was hence selected to provide further information for this site. However, due to the dense vegetation a new survey methodology had to be developed and its results were compared with data obtained using conventional survey practice.



0 50 100 m



Figure 1: LiDAR data of the Iron Age enclosure in Eisenach (LPG LPO, Geobasisinformation of the Vermessungs- und Katasterverwaltung Rhineland-Palatinate, Germany, interpolated to 0.5 m × 0.5 m)

The only viable option for a magnetometer survey appeared to be using a handheld single sensor instrument, for which a Geoscan FM256 fluxgate gradiometer was chosen. Due to the small size of expected features a spatial survey resolution of at least 0.25 m × 0.5 m was deemed necessary. Stationary measurements (i.e. holding the instrument still at each measurement position) would therefore have been too slow and it was necessary to collect data while moving through the vegetation.

The survey area was subdivided into 25 data grids of 10 m × 10 m using tapes and ranging rods since no reliable signals could be obtained from GPS or Total Stations. The start and end positions of each 10 m survey line were marked with small flags of matching colours to help with the orientation while moving through the woods. To avoid obstacles (mostly trees) the start and end positions were then adjusted slightly in such a way that straight lines could be walked, all in the same direction (unidirectional survey; NE to SW). The root-mean-square (RMS) deviation from the correct positions was 0.12 m and 0.36 m for start and end points, respectively (Figure 2). Due to the varying vegetation a constant walking pace could only be maintained for each individual survey line, not for all of them, as is required in conventional survey practice. Therefore during data recording both start and end of each line had to be marked with a handheld trigger, similar to the methodology frequently used with caesium magnetometers. To accomplish this with a Geoscan gradiometer a larger length was selected for the data grids (20 m) and when the recording was stopped, reaching the end of a line, the remaining ‘unused’ data points were filled with ‘dummy readings’. Each stored survey line hence contained a different number of valid measurements.

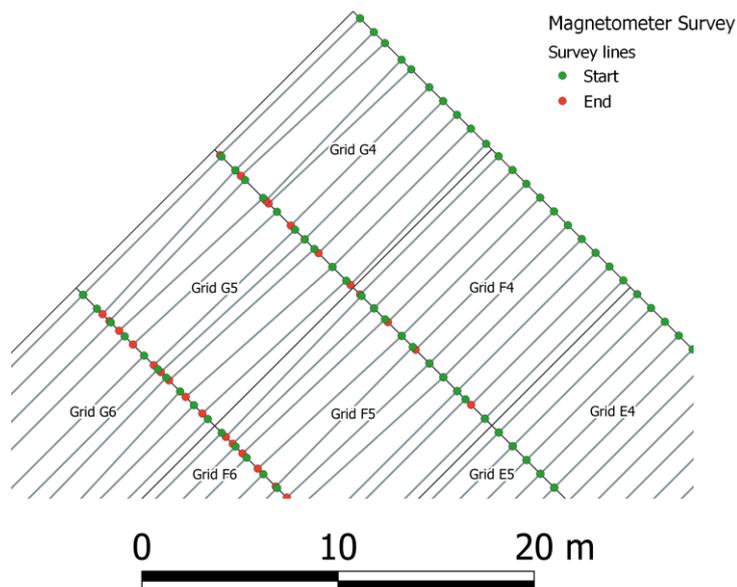


Figure 2: Excerpt of the survey area showing the deviation of start and end positions from a regular raster.

This adjusted data collection methodology required new processing schemes. First, the actual x/y position of each measurement was calculated from the known start and end position of each survey line, and the resulting data set was then interpolated to a regular grid of 0.125 m × 0.125 m. Second, given that the deviation of the survey lines from the correct position was small (see above) the recorded data were re-sampled to 0.125 m and then stored as regular survey lines for further processing in Geoplot, ignoring their slight slanting. A comparison of the results from these two processing schemes showed only small changes in the shape and position of anomalies and the simpler second approach was chosen for further analysis.

In an area where vegetation was low enough to use the standard fluxgate gradiometer survey procedure (same walking pace for *all* lines) a comparison was

made between the new adjusted methodology, and the usual uni-directional and bi-directional collection. There were no discernible differences in the data.

The final survey data for the site were dominated by many small and weak anomalies (Figure 3a) that are presumably caused by ammunition, since the woods were used as a shooting and training area for the Belgian army after the Second World War. Due to the strong screening effect of these ferrous anomalies there are no anomalies visible that could be attributed clearly to Iron Age habitation remains, even when masking all those weak anomalies that have peak values in the range 1-3 nT (Figures 3b and c).

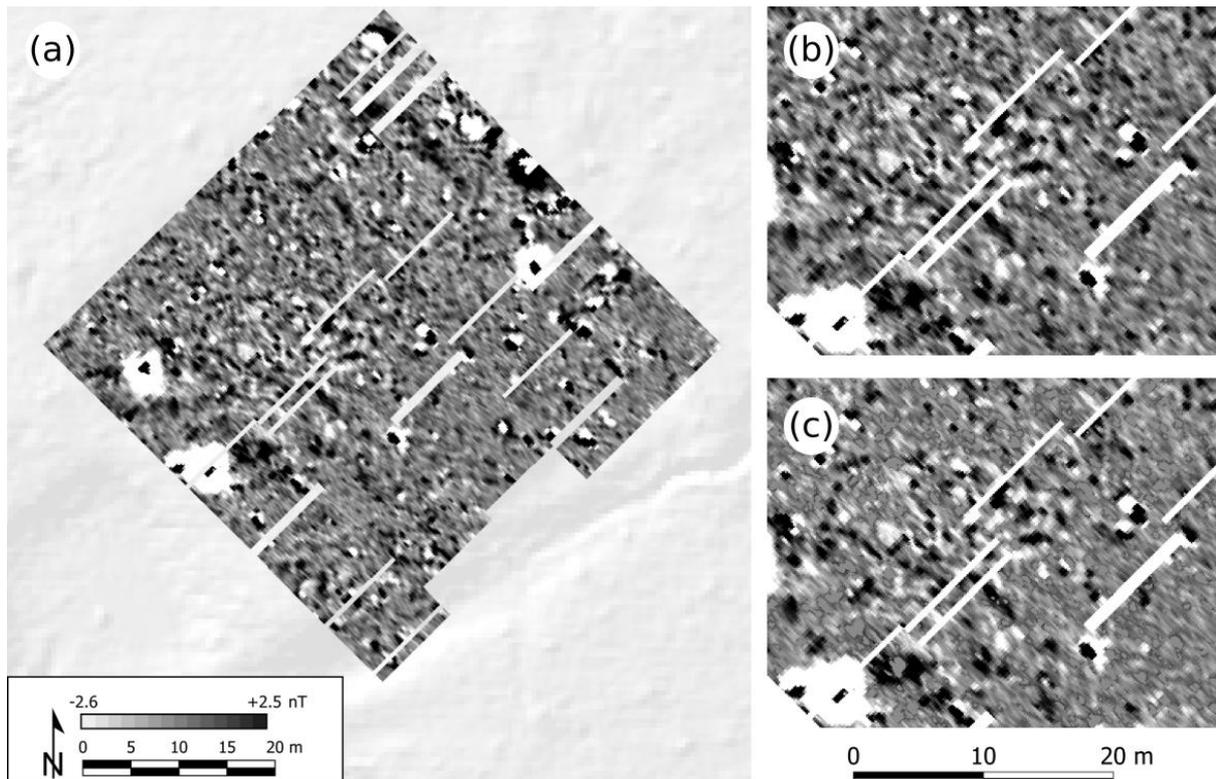


Figure 3: (a) Overview of all data; (b) excerpt; and (c) excerpt, anomalies with peak values between 1-3 nT masked in grey.

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## LARGE SCALE GEOPHYSICAL INVESTIGATIONS OF THE MEDIEVAL MANOR OF AUSTRÅTT IN MID-NORWAY – COMBINING METAL DETECTING, GÅR AND MAGNETOMETER SURVEYS

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### Introduction – metal detecting assemblages from Austrått

The Manor of Austrått is one of Norway's oldest manors and has been the home of a long line of chieftains, earls, noblemen- and women dating back to the 10<sup>th</sup> century. Recent archaeological discoveries indicate that its history predates written sources and stretches back to the older Iron Age.

In 2015 and 2018, the county archaeologists in Trøndelag, in collaboration with Ørland Municipality, initiated metal detecting rallies focusing on the manor gardens and the fields surrounding the main manor buildings down to the present-day shoreline towards the Trondheim Fjord. This resulted in the discovery of about 450 artefacts dating back to the older iron age until the early 18<sup>th</sup> century. About 80 were older than the late Middle Ages and involved iron brooches, a folded runic letter in lead, finger rings, a Viking-age key, a rod for a scale weight, led weights and a weapon crest from the 15<sup>th</sup>-century archbishop Bolt and his family. All of these tell a varied and long tale of activity indicating possible trade, burials, settlements and more. However, it is hard to discern purely based on the artefacts what kind of activity the finds might represent. This is why this site is chosen as one of several case study areas for the research project "PastCoast", funded by the Norwegian Research Council.

### The PastCoast-project – using geophysical methods to understand metal detecting assemblages

The PastCoast-project is a multidisciplinary project funded by the Norwegian Research Council, investigating coastal Iron Age site known from metal detecting assemblages. Ultimately the project aims at studying changes and breakpoints in the utilisation of prehistoric marine coastal environments, identifying possible causes for changes and creating an interpretive framework to identify possible human responses to changing environmental settings (Stamnes, 2022). There is an untapped potential to use large-scale geophysical surveys combined with small-scale excavation to understand sites known mainly from metal detecting assemblages. One of the main objectives of the PastCoast-project is to survey a series of sites known mainly from metal detecting assemblages by large-scale highresolution GPR and Magnetometer-surveys, and investigate 1. If we can detect subsoil features at these sites, and interpret them from an archaeological perspective, and 2. Determine if there is a spatial relationship – both in a local and regional perspective, between the finds assemblages and subsoil features. This will help characterise these sites and improve our cultural-historical understanding of their context and significance.

## Geophysical Surveys at Austrått – surveys and results

The geophysical investigations performed at Austrått involves both large-scale GPR and magnetometer surveys. All in all, about 5.4 hectares of GPR data has been collected using the Kontur (previously 3d-radar) GPR with a ground-coupled antenna array with an inline and crossline spacing of 7.5 centimetres. A 3.4 hectare magnetometer survey then followed this up with a crossline spacing of 25 centimetres using a towed 16 channel Sensys MXPDA magnetometer array.



Figure 1: GPR surveys at Austrått. Photo: Arne Anderson Stamnes

The GPR investigation revealed a wide range of geophysical responses, where some are clearly of cultural-historical significance, while others are more difficult to interpret. The surveys also reveal many modern features in the form of infrastructure and drainage patterns.

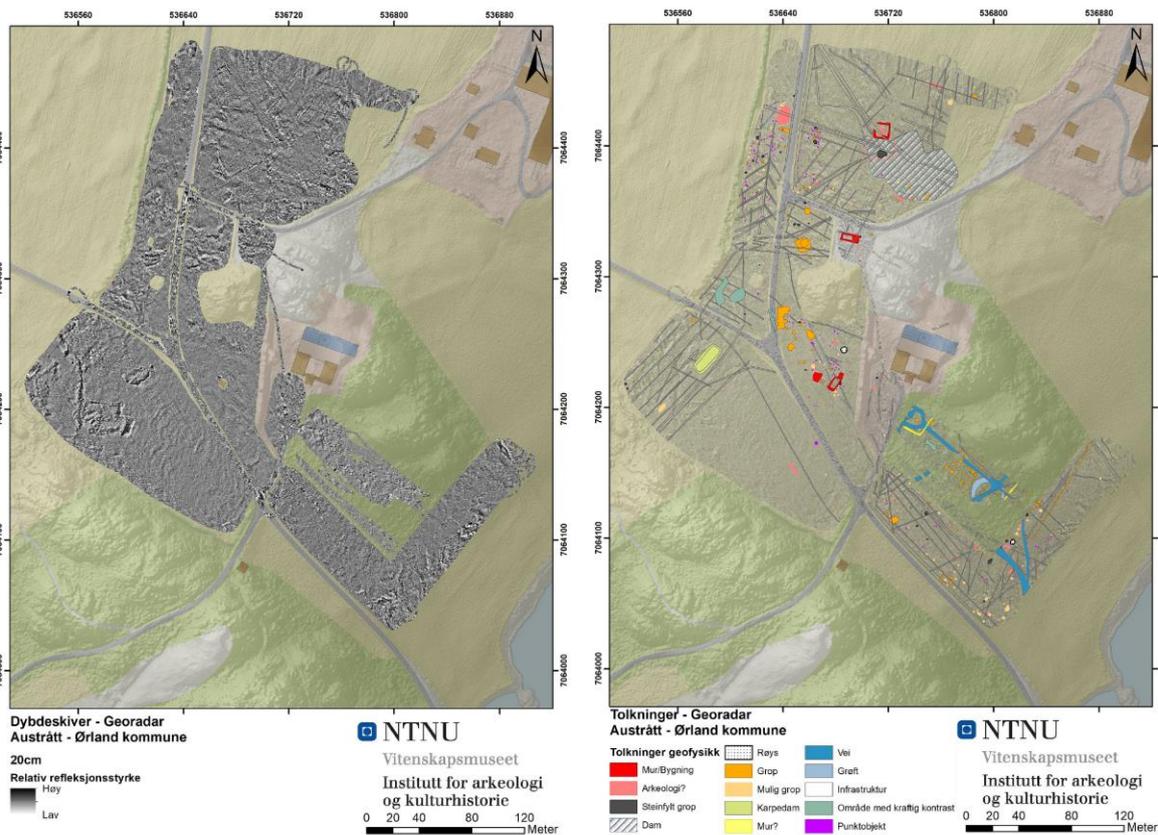


Figure 2: GPR results and interpretation from Austrått.

At least four anomalies are interpreted as house-foundations, where one is assumed to be the remains of the old medieval manor house. This geophysical response is about 12x7.5 meters, and have a signature typical for stone-built walls. These must have been significant in size and height, as they are from 1 to 2 meters wide in some places. This area also has a significant magnetometer-response. A key dated to Viking- or early medieval times was found nearby.

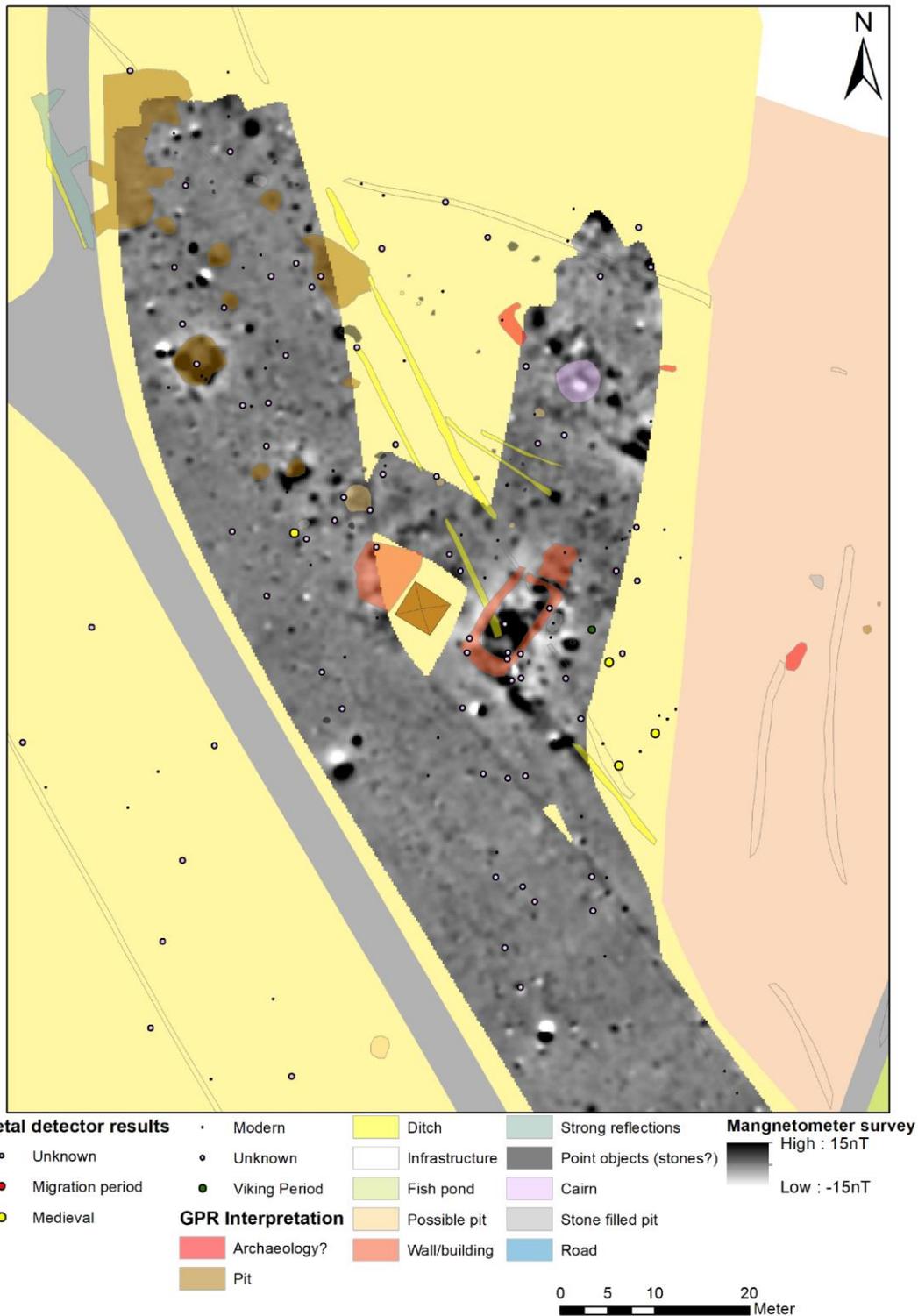


Figure 3: GPR interpretation, magnetometer plot (+-15 nT, black is positive), and distribution of metal detecting finds surrounding the possible manor-house.

The investigations also resolved the location of a medieval fish pond. Several other larger responses interpreted as ponds were located, and prominent garden-archaeological features, including footpaths, trackways, and pits from renaissance-shrubberies later removed. The survey from the garden area also revealed a circular ditch shape enclosing an area of approximately 19m in diameter, possibly from a previously unknown iron age burial mound.

A total of over 300 possible pits were interpreted, of which 30 were classified as stone-filled pits. Such reflections at other surveys often revealed prehistoric cooking pits (Gustavsen, Stamnes, Fretheim, Gjerpe, & Nau, 2020). Some of these have a distinguishable magnetic response supporting this interpretation.

### **Summing up – comparing metal detecting finds and geophysical survey results**

The geophysical surveys revealed many interesting reflections and geophysical responses, some of which reflect the presence of significant archaeology. The survey results indicated several previously unknown building remains, any of which reflects the Medieval and more recent Renaissance activity on site. Combined with the metal detecting assemblages, they tell a story of trade, settlements and prominent landscape reshaping in the form of the renaissance garden. However, in addition to this is the identification of a possible ring ditch from a burial mound. Several iron age brooches tell a tale of iron age burials and settlements in the landscape. This gives the site an additional time depth of at least 4-500 years, dating back to the 5<sup>th</sup> century or possibly older. The stone-filled pits, if cooking pits, might be of the same age or older.

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# AFTER THE BIBLICAL FLOOD: MAGNETOMETER PROSPECTING AT FARA (IRAQ) TO ASSESS THE EXCAVATIONS AT ANCIENT ŠURUPPAK FROM 120 YEARS AGO

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## Introduction

The modern site of Fara, appears at first glance rather „impressive“, but it hides the remains of one of the major Sumerian cities of Mesopotamia of the third millennium in plain sight: ancient Šuruppak. Šuruppak is named as the seat of the last dynasty „before the flood“. Its King Utnapištim / Ziusudra, biblical Noah, is said to have built the ship to evacuate his people to save them from the „Mesopotamian Flood“, the biblical Deluge, which is mentioned in the Sumerian King List. Findings date it back to the Jemdet Nasr period around 3000 BC with a continuous occupation until the end of the Ur III period around 2000 BC. Fara was first explored and excavated by the Deutsche Orient-Gesellschaft in the years 1902 and 1903 under the direction of Walter Andrae and Robert Koldewey. Multiple excavation trenches with lengths up to 900 m transected the 1 km<sup>2</sup> wide pear-shaped mound and are still visible today. Unfortunately, thousands of deep looting pits are also present covering the majority of mound. Though the German excavation unearthed 1000 cuneiform tablets, some questions are still open today: Did a city of this importance really had no city wall? Where was the temple of the city goddess Sud? These were the reasons to commence magnetometer prospecting at Fara in the framework of the Fara Regional Survey Project FARSUP (Otto & Einwag, 2020).

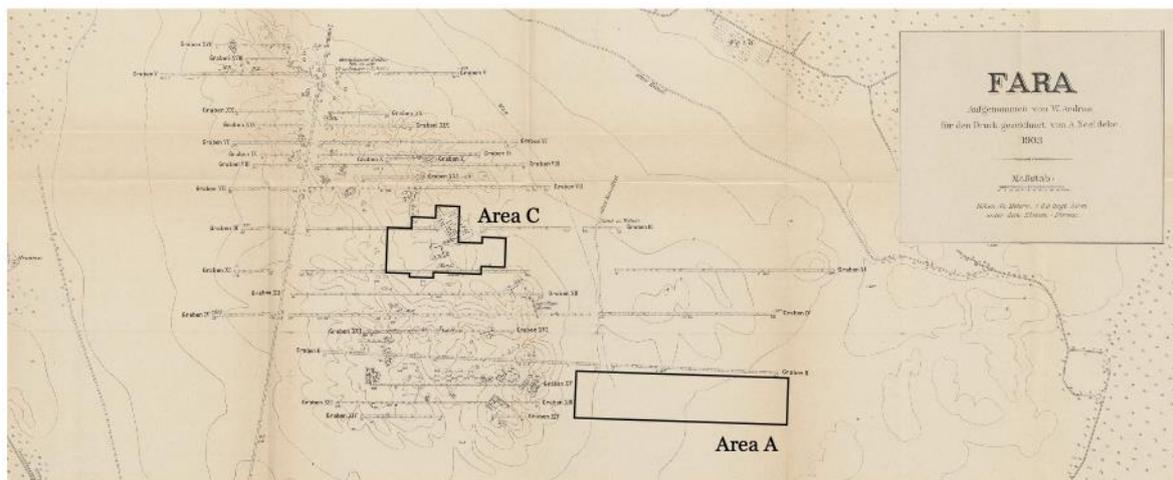


Figure 1: 1903's overview map of Fara, the excavation trenches and architectural findings, modified after Heinrich & Andrae (1931) with the locations of our magnetograms.

## Method

The magnetometer survey in Fara was conducted in 2018 with two total field magnetometers Scintrex Smartmag SM4G-special magnetometer and a Geometrics

G-858 magnetometer, applied in duo-sensor configuration, as well as a Foerster Ferex vertical vector gradiometer instrument. Each survey area was separated into three adjacent segments which were surveyed by a different magnetometer at the same time. The resulting data sets were merged into one magnetogram during the data processing: First the total field data were corrected for the diurnal variation and an image high-pass filter (R=10) was applied which removes larger spatial wavelengths. By multiplying the data of the gradiometer by a factor of two, we compensated for the lack of signal strength of the gradiometer compared to the total field magnetometer. The output of this method is a visually uniform magnetogram which significantly simplifies our visual interpretation since features were easier to trace and compare over the different segments.

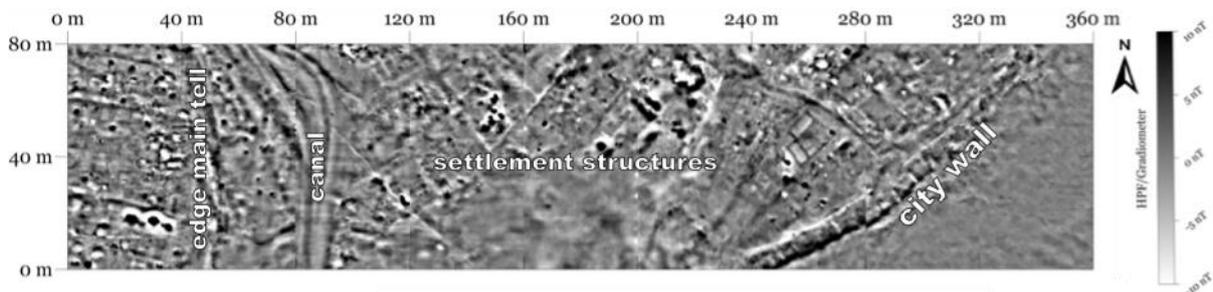


Figure 2: Magnetogram of Area A.

## Results and Discussion

Area A lies to the south, 5 to 10 m distant from trench II (see Fig. 1). Both, the magnetogram (Fig. 2) and the drone images after rainfall show streets and the ground plans of houses with several rooms and courtyards. It is therefore puzzling why there are no descriptions by Andrae of the architectural structures found in trench II or on this eastern mound in general, or why the excavation trench stopped at this eastern point. With our results, though, we have the answer to Andrae's posed question, whether the search trenches extended far enough into the periphery of the tell to trace the city wall! They missed the city wall by a few meters only. It is traceable over a length of 140 m in the magnetogram, oriented south-west to north-east and has a slightly convex curved shape. The width of the city wall's anomaly ranges from around 6 m to 11 m. The city wall seems separated in different sections by transversal interruptions in the feature, forming a pattern comparable to either a "Kastenmauer" or a casemate.

For Area C (see Fig. 3) we compare our results with the details of the building excavated in trench III a-c and its drawing. The approximate location of the building is provided by Andrae's overview plan, and with the help of the anomalies featured in the magnetogram we were able to georeference the drawing. Andrae already mentioned the uniqueness of the building, as all its walls were built with baked bricks, which explains their good visibility in the magnetogram. Apparently though, the visibility of features also depends on the state of preservation of the walls. For example Room 1: the southern wall is traceable in the magnetogram in its entire

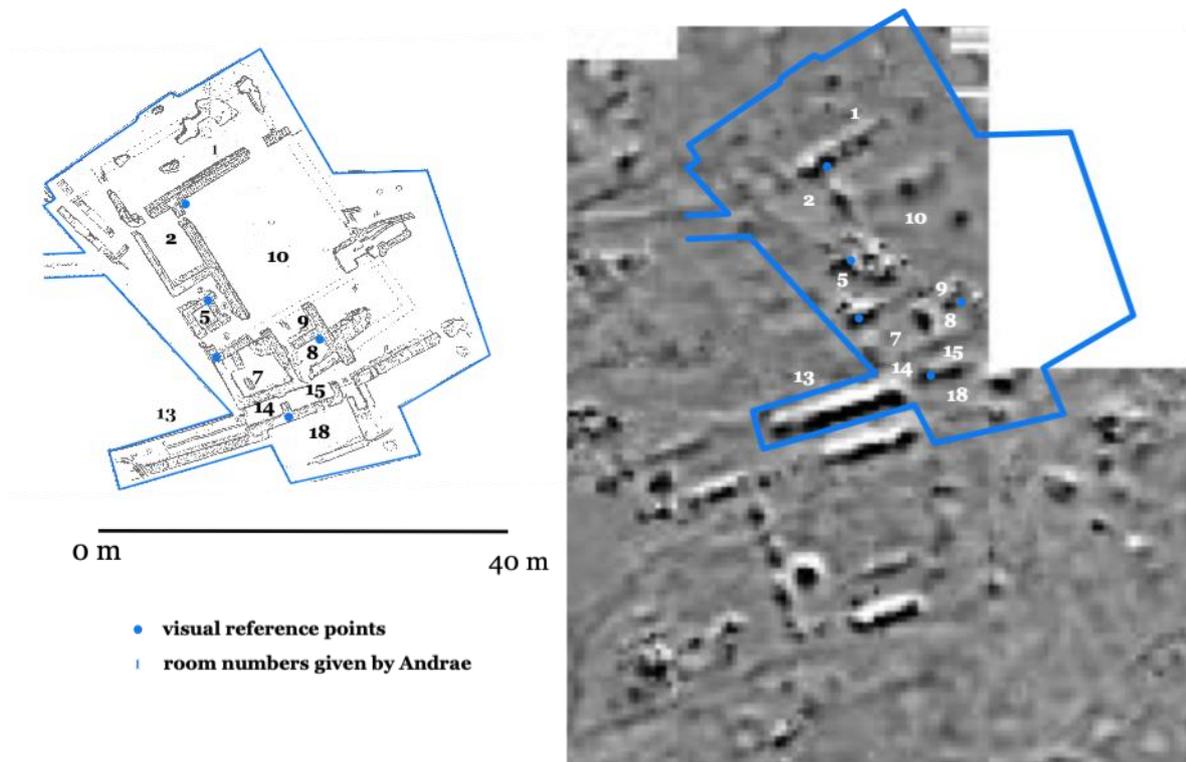


Figure 3: Comparison Area C of the map of the building in trench III a-c (Heinrich & Andrae, 1931, Tafel 5) with the magnetometry. The numbers refer to the room numbers given by Andrae and are displayed here enlarged. The blue dots serve as visual reference points which have the same geographic coordinates.

length. The small wall segment in line with this longer wall is also recognisable in the magnetogram. Andrae sketched these two walls in his drawing as constructed throughout with small bricks. This implies a good preservation upon excavation and, based on the magnetogram, a good survival until today. The western wall of the room was only hinted by Andrae with a few bricks. Its traces are barely visible in the magnetogram. These facts together imply a less good state of conservation even in Andrae's time. The magnetogram complements the excavation results with some further features, among others, a road.

### Conclusion

The case study of Fara shows, that magnetometer prospection can offer new insights into already partly excavated sites and can, like here, answer a hundred years old question regarding the existence of a city wall. The comparison to the old excavation reports and maps shows good correlation with our magnetometry results, especially regarding intact baked brick walls, proving a good preservation of these features and vice versa. The results of the magnetometer survey bear testimony to the accuracy and richness of details of the excavation maps drawn by Walter Andrae. The continuation of the magnetometer survey at Fara has the potential to add further and more detailed insights into the settlement structure, which will hopefully be complemented by future excavations.

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# 3D GPR SURVEY IN THE RECOGNITION OF RELICS OF PRE-WAR BUILDINGS FOR THE RECONSTRUCTION OF THE SAXON PALACE IN WARSAW (POLAND)

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## Research background

In terms of spatial resolution and data acquisition speed, multi-channel GPR systems offer incomparably greater possibilities than the single-antenna GPRs which are most commonly used in Poland (Gaffney et al., 2018; Trinks et al., 2018; Verdonck, Launaro, Vermeulen, & Millett, 2020). The urban environment is one of the most challenging for the GPR method. Various sediments and deposits might cause signal attenuation or scattering, not to mention the omnipresent sources of electromagnetic fields, logistic issues or obstacles disturbing the GNSS positioning. However, even in such unfavourable conditions, the GPR method has proven its usefulness (Kay et al., 2021).

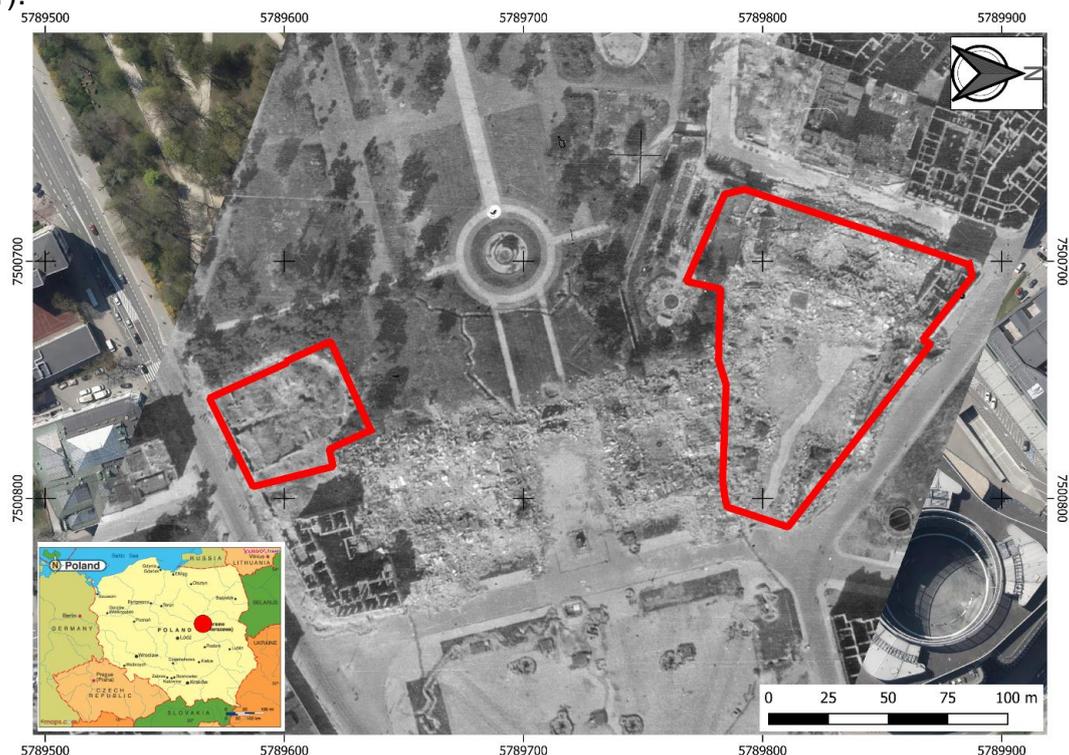


Figure 8: The location of the GPR survey overlaid on the calibrated 1945 aerial picture of razed Warsaw. The northern polygon marks the Brühl's Palace sector and the southern marks the sector of houses at Królewska Street. Coordinates are given in the Polish National CS92.

An example of the high effectiveness of the 3D GPR method applied in such challenging city-centre conditions is the results of the research conducted by the team from the Faculty of Geology, University of Warsaw, in Spring 2022. The research was carried out in the area of the planned reconstruction of the Saxon

Palace, in the very city centre of Warsaw. It aimed to recognise the potential remains of the buildings razed by Nazi Germany during World War II, namely the Brühl's Palace (pre-war building of the Polish Ministry of Foreign Affairs) and tenement houses at Królewska Street (Figure 1).

## Method

The measurements were carried out using the ImpulseRadar Raptor-45 3D GPR system (450 MHz). The system comprises an array of five transmitters and four receivers, allowing simultaneous measurement of eight GPR profiles with a crossline between them of approx. 8 cm. Sampling along the profiles was set to 4 cm. The measurements were recorded along with their location provided by the GNSS RTK 800-channel Art-Geo Sirius receiver. The survey was carried out in Spring when trees were still leafless. This allowed us to keep the measurements being carried out mostly with a fixed solution, despite the Saxon Park offering not the perfect surveying conditions due to the trees. Samples collected with floating or DGNS solutions were later rectified in postprocessing with ImpulseRadar Condor processing software.



Figure 9: Calculated depth slice of the results from the Brühl's Palace sector, presented in OspreyView visualisation with a central depth of 110 cm. In the top right, a pre-war picture of the entrance gate to the palace is shown. The red arrow indicates the perspective of the picture.

## Results

The research was carried out in two areas of the present Saxon Park in Warsaw - in Królewska tenement houses and the Brühl's Palace sectors. The high-fidelity GPR survey revealed zone and linear reflections, which allowed us to delineate not only the searched structures but also contemporary and old infrastructure (Figures 2 & 3). The quality and resolution of the data allowed us to distinguish even very small-scale structures, like the possible remains of the arcade of one of the outbuildings of

Brühl's Palace. Thanks to the considerable depth of prospection (up to 3 m below the surface level) it was possible to indicate the preserved basements of Brühl's Palace.



Figure 10: Calculated depth slice of the results from the Królewska tenement houses sector, presented in OspreyView visualisation with a central depth of 160 cm. In the bottom left a pre-war aerial picture of the houses is shown. The red arrow indicates the perspective of the picture.

## Conclusions

In both areas, the 3D GPR method proved to be effective, both in the identification of underground relics of the pre-war building remains, as well as linear infrastructure. Despite the challenging survey conditions (i.e. the presence of trees, contemporary infrastructure and tertiary sources of electromagnetic fields) 3D GPR has proven to be an effective tool for pre-development archaeological research even in the city centre.

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## TRACING ROMAN GRAVE MONUMENTS IN RUFFENHOFEN (BAVARIA, GERMANY)

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### Introduction

Often graveyards are neglected during geophysical surveys of Roman sites like fortresses and vici. However, these structures are quite important parts of such sites. Here we present an integrated survey with magnetometry and ground-penetrating radar (GPR) of several monumental Roman burials.

The Roman fortress of Ruffenhofen (Bavaria, Germany) is located ca. 2 km south of the Rhaetian Limes on top of a slight hill and was occupied between the beginning of the 2nd century AD and the middle of the 3rd century AD (Czysz et al., 1995; Sommer, 2007). As Ruffenhofen depicted the largest and most important fortress in this part of the Limes, a huge vicus surrounded it (Czysz et al., 1995). In total, the site covered an area of ca. 27 hectares as the geophysical surveys revealed.



Figure 11: Section of the magnetogram in Ruffenhofen showing the relevant part with the Roman grave monuments. Scintrex SM 4G-Special Caesium Magnetometer, duo-sensor configuration, sensitivity:  $\pm 10$  pT, dynamics:  $\pm 10$  nT in 256 greyscales, sampling rate: 50 x 25, interpolated to 25 x 25 cm, 40-m-grid. Archive-No. Ruf00b.

The grave monuments that are topic of this abstract are located ca. 350 m northeast of the fortress along the road from the porta praetoria towards the east (Pausch, 2009). They were already detected in 2000 by a caesium magnetometer survey (Fig. 1). In addition, in 2022 a GPR survey was executed to further improve the interpretation map of the constructions and monitor the state of preservation in the subsoil.

### Result of the geophysical surveys

The archaeological remains of the Roman grave monuments are located quite shallow in a depth of only 30-90 cm below the modern surface (Fig. 2). Hence, it is important that the area of the Roman site is taken out of cultivation since 2001, as the stone walls otherwise would have been destroyed by ploughing.

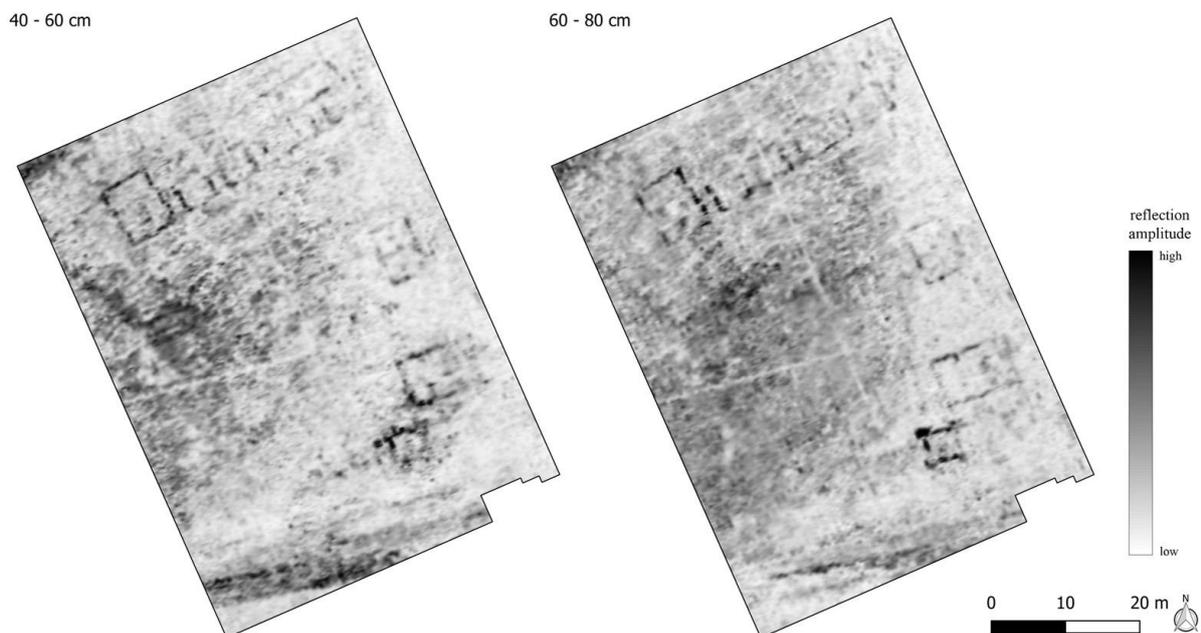


Figure 12: Selection of GPR depth slices between 40 and 80 cm below modern surface. GSSI SIR-4000 with 400 MHz-Antenna, 6cm trace interval by 50 cm traverse interval, interpolated to 25 x 25 cm. Archive-No. Ruf22rad.

In the northern part of the survey area, a row of five grave monuments is visible. The exact orientation along an axis suggests another Roman road in this area that cannot be verified anymore by geophysical prospection. The westernmost monument has a size of 9x7 m (Fig. 3, No. 1) and is structured into two rooms, a so-called pronaos in the north and a cella in the south. Inside the cella, a preserved ash box or sarcophagus of 1.5x1 m size can be identified as a rectangular high reflective anomaly in the GPR data. As there is an enhanced magnetic anomaly at the same position, the cremation still seems to be inside. Also in the pronaos another cremation grave is visible that possibly dates earlier and was later overbuilt by the stone monument. Based on its shape, this structure could depict a temple grave as known from Kempten-Cambodunum (Bavaria) or Lovech (Bulgaria) (Fig. 4a) and described in Scholz 2012.



Figure 13: Georeferenced interpretation map based on the geophysical survey results. The numbers refer to the text. Colour coding: orange = stone grave monuments, magenta = cremation graves, black = survey grid outline. GIS-Plan No. L 6928/074.

East of this temple grave, four mainly quadratic grave enclosures between 4x4 m and 5x7 m size were erected (Fig. 3, No. 2). For these monuments, it is difficult to interpret them either as open stone fences or roofed temples. The small size indicates walled fences (Latin: *viridarium*). This thesis is supported by the fact that the magnetogram does not show bigger concentrations of burnt bricks as remains of a roof. Similar rows of small fenced graves are known from Kading-Virunum (Austria), Sontheim an der Brenz (Germany) and especially Mainz-Mogontiacum (Germany) (Fig. 4c) (Scholz, 2012). Normally such *viridaria* were closed fences and could not be entered.

South of this prominent row of graves, several single constructions appear in the data. Two of them (Fig. 3, No. 3 & 4) resemble No. 1 and therefore probably were temple graves as well. The central wall separating the *pronaos* and the *cella* in No. 3 is only visible in 40-60 cm depth in the GPR data and not additionally in 60-80 cm depth like the outer walls. Hence, it possibly was only a sill and not a wall like in No. 1. No. 4 shows a central high reflective anomaly in the middle of the *cella*. Due to the huge size of 2.5x1.5 m, the structure is possibly too big for an ash box or sarcophagus. That makes the interpretation as a sepulchral stele or base of a statue more favourable.

The southernmost two graves are situated at the above mentioned known Roman road from the fortress towards the east. The eastern one is most likely another *viridarium* of 8x8 m size (Fig. 3, No. 5). As it is much bigger than the normal length of 2-5 m (see No. 2), it is likely that this monument could have had the possibility to

enter the garden. The western one (Fig. 3, No. 6) depicts a special type of grave monument, a so-called grave enclosure in block construction technology like in St. Albans-Verulamium (UK) (Fig. 4b).

In the neighbourhood of the above-described grave monuments, a multitude of further urn graves can be identified in the magnetogram. Partly, they could date earlier than the monuments, partly these could be graves of less wealthy inhabitants of fortress and vicus that could not afford a monumental construction, but only a hedge. The curved anomaly north of No. 1 possibly is the trace of the Roman cremation area, the so-called *ustrina*.

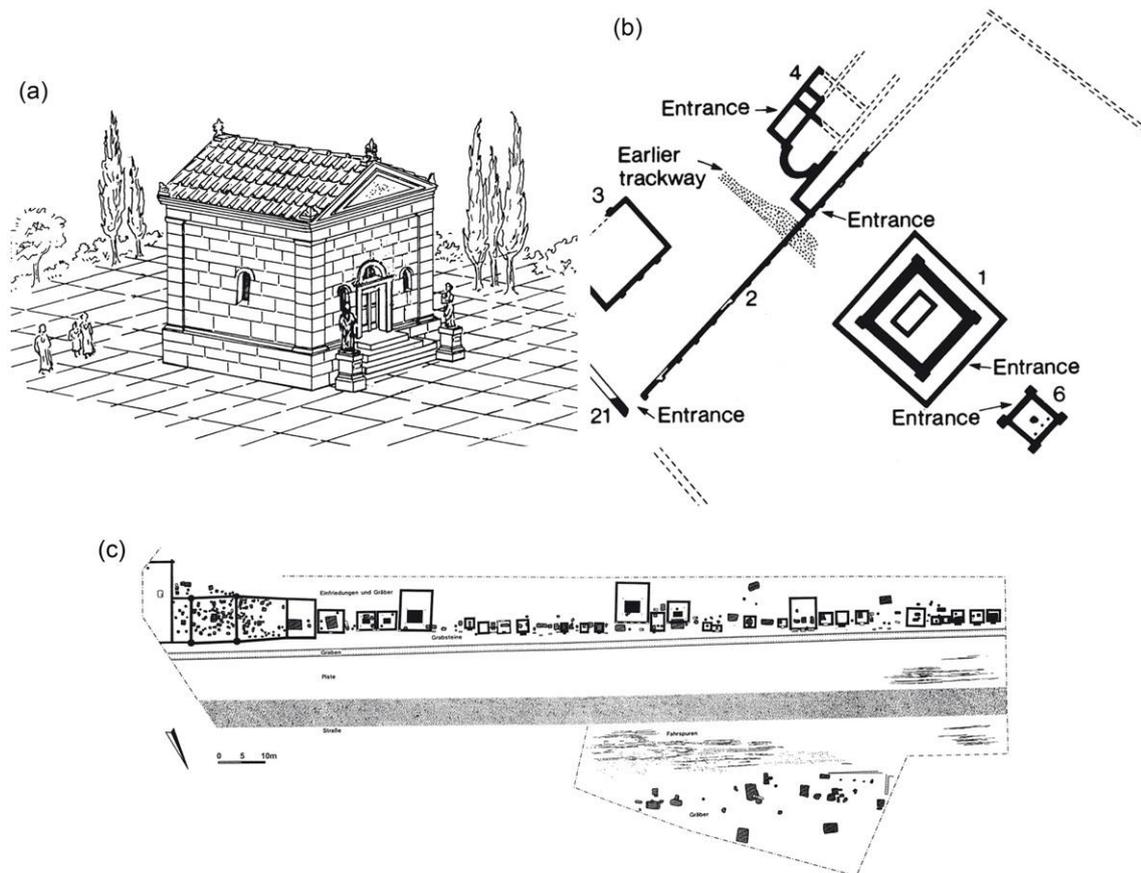


Figure 14: Examples for comparable grave monuments. (a) Reconstruction of a temple grave from Lovech (Bulgaria), (b) Excavation map of the grave district in St. Albans-Verulamium showing a grave in block construction technology (6), (c) Excavation map of the burial road in Mainz-Mogontiacum. (Scholz, 2012; CC BY-SA 4.0).

## Conclusion

The integrated approach of a combination of magnetometry and GPR results in a detailed interpretation map of the grave district in Ruffenhofen. The fact that there had been a combination of *viridaria* that are very common in the Northern Roman provinces and temple graves that are less common, emphasizes the importance of this settlement.

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## GPR AT GORHAMBURY: SURVEYS BY THE COMMUNITY ARCHAEOLOGY GEOPHYSICS GROUP AT THE ROMAN CITY OF VERULAMIUM

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The *Community Archaeology Geophysics Group* was formed in 2013 supported by a grant from the Arts and Humanities Research Council (UK). Since then, the group has gone on to survey over 40 sites mainly in Hertfordshire and nearby counties. The Group's main survey has been at the Roman city of Verulamium where we have now completed over 1km<sup>2</sup> of magnetometry survey, along with Earth Resistance, GPR and magnetic susceptibility surveys. Those in Verulamium Park, the south-eastern half of the city, were published (Lockyear and Shlasko 2017). The project has also maintained a blog from which the majority of the survey results are available ([hertsgeosurvey.wordpress.com](http://hertsgeosurvey.wordpress.com)).

In 2015 the group began a series of summer seasons on the north-western half of the city which form part of the Gorhambury Estate. We were also able to access a Mala GPR from SEAHA, a doctoral training school, and since 2021 have had access to the Institute of Archaeology's machine. We completed the magnetometry survey of this area in 2016, and have been expanding the GPR, Earth Resistance and Magnetic Susceptibility surveys each summer since (with the exception of 2020). We completed the survey of the Gorhambury side of the town in 2022, some 36 hectares.

The survey has been conducted using a Mala GX system with a 450mhz antenna (Fig. 1). GPR data was collected at a 0.5m transect interval over most of the 35ha survey in 40mx40m grids. On the periphery of the town, where the magnetometry survey had previously not indicated any surviving archaeology, the transect interval was increased to 1m. One new building was detected in this area and the building was resurveyed. This season we have resurveyed one building at 0.25m transects as an experiment.

As one might expect in a Roman city, we have detected a wide range of buildings from probable shops (Figure 2) and small, quite modest houses to large grand corridor houses of the type excavated by the Wheelers in the 1930s (Figure 3). The road network has been confirmed, with some road junctions clearly being centres of activity. As presented in ICAP Sligo, there are areas of the town within the walls which appear to have been largely devoid of features. In places, comparison with the magnetic gradiometer data suggests that some buildings had burnt down and not been replaced, probably during the Antonine fire in the middle of the second century AD.



Figure 15: The Mala GPR in action.

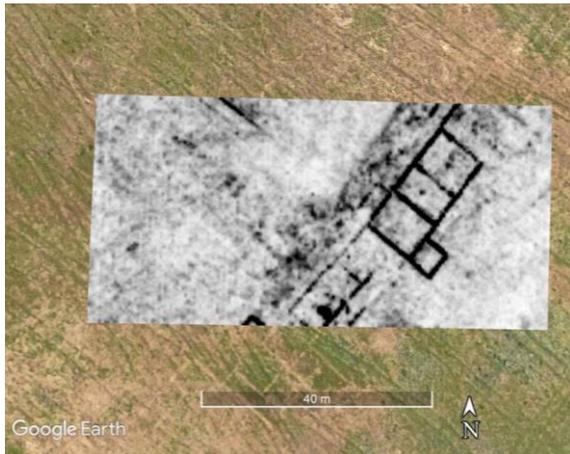


Figure 17: Smaller buildings along the street in Insula XXVII.

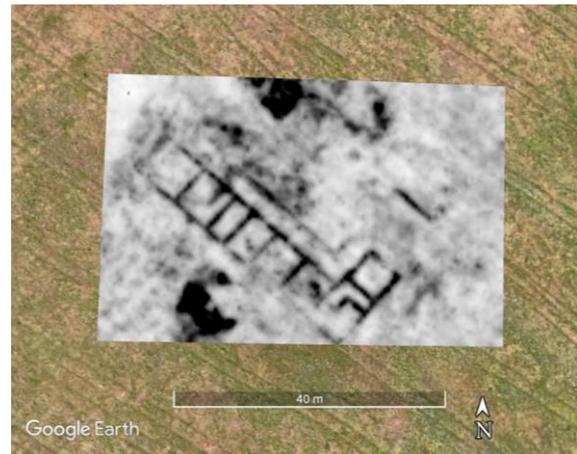


Figure 16: The large house in Insula XXVI, Building 2

The GPR survey has detected buildings which were known from the magnetic gradiometry survey, but has also detected buildings that were not visible in the magnetic data. On the whole, the GPR data and the Earth Resistance data were comparable, although the latter tended to show the roads more clearly than the amplitude slices. For some buildings, such as Insula XXXVII Building 1, the GPR data has revealed additional details not seen previously.

The survey in 2022, however, revealed a series of buildings in Insulae XVII, XXXII and XXXIII which were rather unexpected and are challenging to interpret (Figure 4). These include one with an 80m long frontage and a 60m long colonnade overlooking the River Ver which some have suggested may be a 'palace'. They also include a basilica-like structure on one side of what might be an open courtyard with a heavily buttressed building in the centre, and finally what seems to be a series of smaller buildings within a courtyard. Next to this large complex of buildings is a large open area which contains two Romano-Celtic temples. The magnetic data of this area suggests there may be a boundary ditch. The data is at a very early stage of analysis and interpretation and much remains to be resolved.



Figure 18: New buildings in Insulae XVII, XXXII and XXXIII.

The GPR data now presents a series of major challenges for the group. Firstly, processing the data collected over seven seasons in a manner which minimises the differences between blocks (even within a season) without sacrificing detail is difficult. As well as the amplitude slices, examining and interpreting even a small proportion of the radargrams is a massive task. Secondly, how can we involve more members of the group when we have a single licence of the software? Thirdly, how do we combine the GPR results with the magnetic and Earth Resistance data? Lastly (but perhaps most exciting), can we find parallels for the new structures in order to aid interpretation of them? What does the new data contribute to our understanding of this Roman city?

### Acknowledgements

The group would like to thank the Institute of Archaeology, UCL, for the loan of the survey equipment and software, SEAHA for the loan of their GPR (2015–9), Lord Verulam and the staff of the Gorhambury Estate for allowing and facilitating access, and Mike Langton and Jimmy Adcock for help with the GPR and data processing.

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# OLD AND NEW FRONTIERS: GROUND PENETRATING RADAR SURVEYS AT THE ROMAN FORT OF TRIMONTIUM

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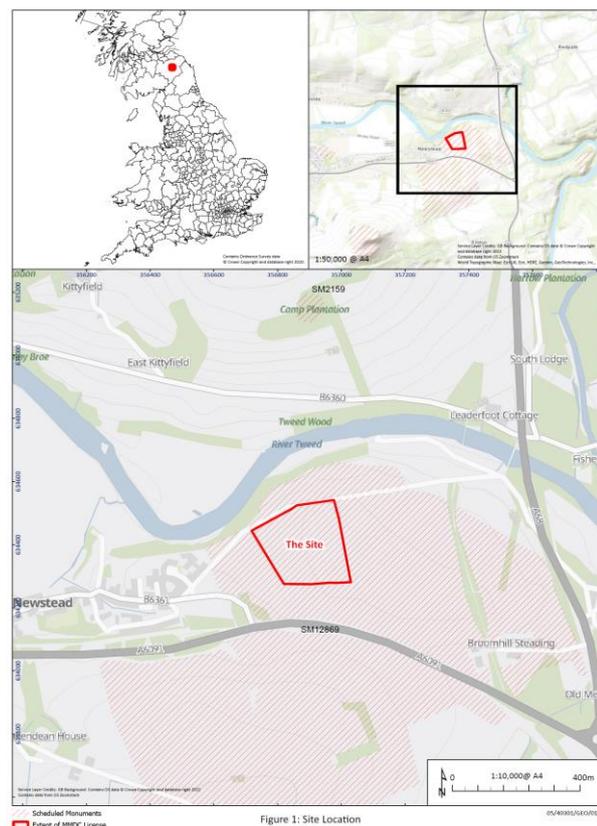
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## Introduction

The scheduled monument designation that protects the site of the Roman fortress of Trimontium, at Newstead, near Melrose in the Scottish Borders (SM12869) comprises a series of four overlying forts; seven annexes which occur on all four sides of the forts; at least six camps; one bathhouse; and a possible amphitheatre.

Between 1905 and 1910, one of the largest Roman military complexes in Scotland was excavated at Newstead by local antiquarian James Curle. The unique series of enormous pits (related to the speedy final abandonment of the complex) demonstrated that Trimontium was an auxiliary cavalry fort from which mounted troops could be deployed rapidly into the surrounding countryside. Evidence for the presence of horses abounds in the form of horse harness remnants, horse skeletons and most dramatically of all the wonderful cavalry parade helmets.

The complex consists of at least four phases of construction during two or more periods of occupation, which occurred during the late 1st and mid-2nd century AD. It was excavated between 1905 and 1910 by local archaeologist James Curle, and the resulting publication in 1911 (Curle, 1911) was ahead of its time, exploring not just the fort but its relationship to its hinterland and the interaction between Roman and local peoples. Curle's work was verified and clarified by limited excavation work in 1947 by Sir Ian Richmond, and extensive aerial photography work on cropmarks led by Dr JK St Joseph during the same decade (Trimontium Trust, 1994). The site was also the focus of a research project by Bradford University from 1989 to 1997, with a series of



the north of the main fortification and the discovery of the amphitheatre in the same area (Clarke, 2000, Clarke & Wise, 2000).

The first incarnation of the fort was an irregular fortification established in around 80AD during the reign of Agricola. The fort had a cobble and turf rampart with double external ditches that overlapped the entrances at the cardinal directions. There was also a western annexe of similar construction. The first fort seems to have only been in temporary use, for perhaps around a decade. After a short possible abandonment, between 90AD and 105AD there was an extensive period of construction with large turf and cobble ramparts being constructed with a single ditch, and the old ditches filled. The new defence works were substantial, with a cobble base for the turf ramparts which were c13m wide and c8m high, with the ditch being cut to 2-4m depth and 5-7m wide. Between 105AD and around 147AD the fort was again abandoned, though it is possible it was briefly reoccupied prior to the Antonine advances north of Hadrian's Wall. After 142AD during the period the construction of the Antonine Wall, the site was occupied again and there is evidence that the main entrance was now routed through the southern annex, which was occupied by a civilian population.

### **New Ground Penetrating Radar Surveys**

This paper presents the early results of new GPR surveys conducted at the site in spring 2022 as part of a community archaeology partnership between AOC Archaeology Group, the Trimontium Trust and GuidelineGeo and their UK partner Sygma Solutions. Over 5ha of the interior of the main fort complex was surveyed using a Mala Mira 3D GPR array, covering two warehouses, the *principium*, the garrison commanders house and possible barrack blocks, as well as the southern entrance. At the same, as part of a field school a 60m x 60m block of GPR data was collected using a MalaGX system with a 500 MHz antenna, with 0.5m line spacing. This was entirely collected by volunteers from the trust under the supervision of AOC Archaeology staff. They designed the survey to fit their aims – confirming the location of the western annexe containing the bathhouse and examining the outer defence circuit.

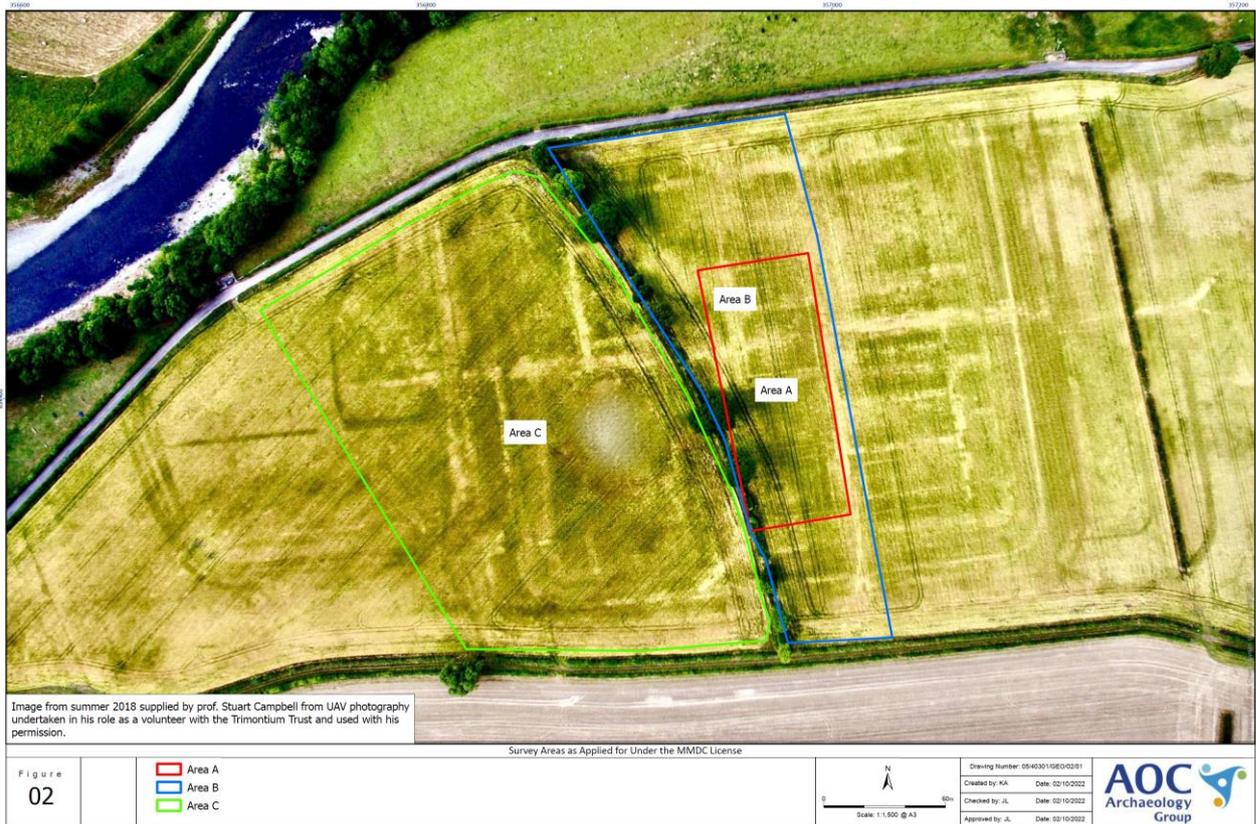


Figure 2: Location of survey areas

## Results

The results of both instruments are excellent, with good signal penetration and clear visualisation of buried archaeological features. The local soils and geology have had no negative impact on the survey results. The continuous use of the site for agriculture has resulted in a survey environment largely free of responses related to recent disturbance or modern infrastructure, though the repeated excavations on the site have possibly resulted in some differences in the character of the soils. Both surveys have clearly demonstrated that there are archaeological features still present within the survey area (Figure 1, Figure 2), and that these are within reach of the current ploughing regime. The surveys have both confirmed and challenged published plans of the survey areas, with the major public buildings identified in excavations ready identified in the results. However, the results also show evidence of structures not seen on published plans, suggesting these are incomplete and somewhat schematic, rather than records of the below-ground environment.

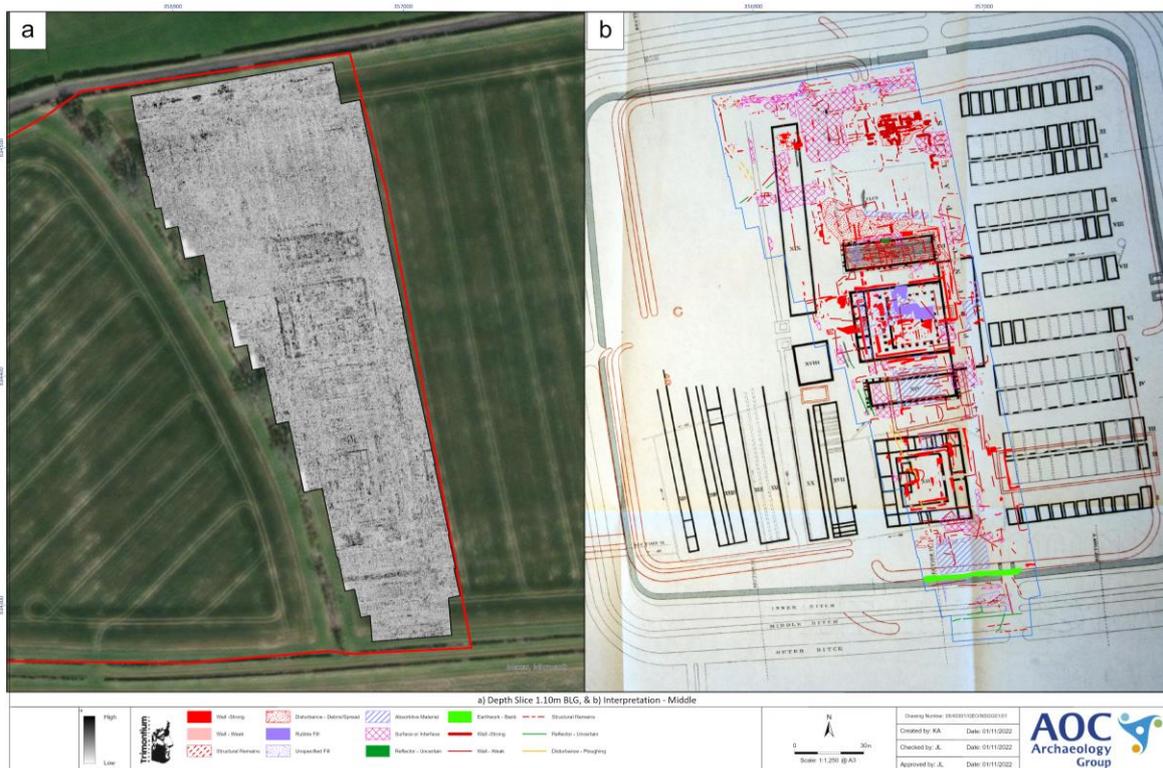


Figure 3: GPR amplitude slice and interpretations for Area B, 1.1m below ground level.

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## REMINISCENCES ON 30 YEARS OF MAGNETIC SURVEYING (MOSTLY) IN THE UK

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What my talk will NOT be about is a history of magnetic geophysical survey in the UK, as this has already been done extremely well by people with much more experience than I could muster on the subject. Rather, I intend it to be a personal look back over my own three decades of surveying, pulling out some points of interest along the way.

Firstly, high resolution survey, is it worth it? I will be looking back at a number of tests I did over the years and coming to some conclusions (though they may be contradictory!). I will also address the concept of what high resolution actually entails, as it appears to mean different things to different groups.

Secondly, how does the application of “green waste” on fields in England affect the results of magnetic geophysical surveys. Perhaps “green” doesn’t always mean Green!

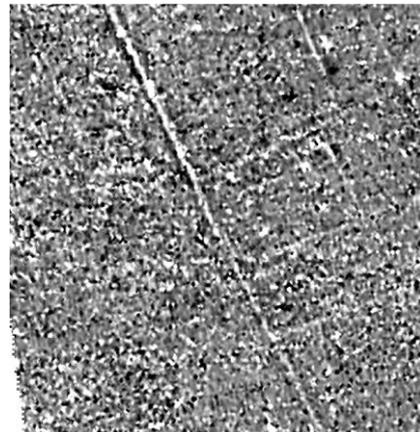


Figure 1: Impact of green waste deposition

Serendipity in geophysics, where things come together in ways which may not have been foreseen, or you are just in the right place at the right time. When you get to a certain age, there are a number of moments you can look back on and realise that they were the ones that counted, even though you could not have been aware of the significance of them at that time.

Geophysical epiphany (I’ll have to explain this one on the day).

I will also be assessing my work with local community groups, something I am being increasingly asked to do, and seeing how far these groups can proceed by “flying solo”. This is a phenomenon which is particularly prevalent here in the UK, though of course this also happens across the globe.

Finally, I will be taking a look at how commercial geophysics in the UK has changed over the years, and the impact that this change has had on budding geophysical surveyors trying to get into the field.

## POSTER ABSTRACTS

### TOUCHING THE PAST: TACTILE MODELS OF GEOPHYSICAL IMAGES FOR IMPROVING USER ACCESS TO ARCHAEOLOGICAL DATA DISPLAYS

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The advantages of geophysical imaging are widely appreciated by the archaeological community, both as a means of detecting potential targets and conveying the archaeological significance of a site to an interested audience. However, unlike archaeological artefacts, the presentation of geophysical data is entirely visual and thus cannot be fully appreciated by those with visual impairment. Museum services are increasingly invested in maximising access to exhibitions, and the appreciation of geophysical data risks being overlooked in inclusivity initiatives. Do tactile representations of geophysical data provide a means of broadening accessibility?

This project aims to develop a procedure for converting geophysical data into a textural surface, and then solicit feedback through focused user groups. Currently, we have fabricated textural prototypes based on GPR data (Figure 1, left) acquired over the foundations of a gasworks at the industrial village of Elsecar, South Yorkshire. The survey used Sensors&Software pulseEKKO PRO antennas of 500 MHz centre frequency, and spanned a 16 x 40 m area (0.25 x 0.02 m trace density). The main features in timeslices show the circular perimeter wall of a gas holder and the rectilinear foundations of related buildings (Figure 2, right).

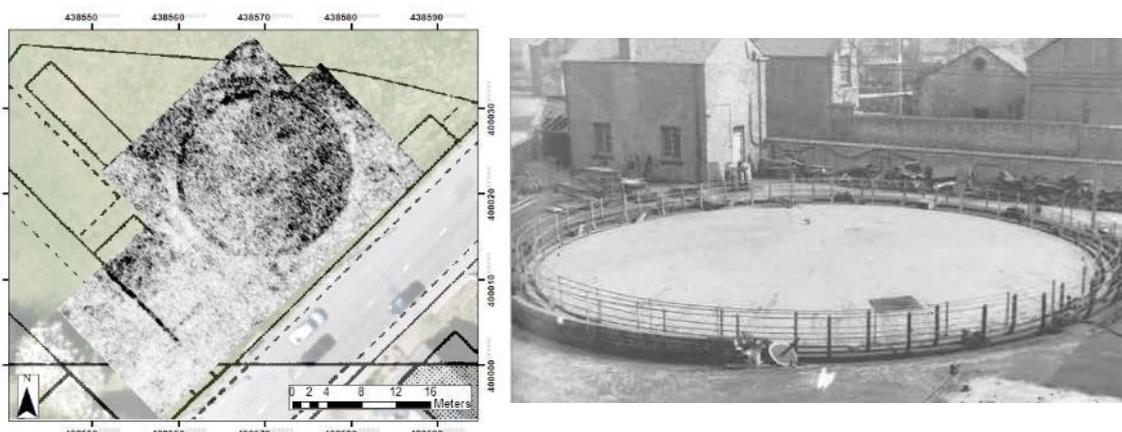


Figure 1. Left: GPR slice (~86 cm depth) over gasworks foundations at Elsecar, South Yorkshire, with 1930s OS overlay and BGS satellite imagery (BNG (m) coordinates) (Frandsen, 2018). Right: Elsecar gas holder and associated building: photograph looks south across the survey area (EH & A Stenton).

A standard set of GPR processing routines was applied, including enveloping of traces and amplitude averaging in a 1 ns window. Greyscale images of timeslices were then supplied to a laser cutting instrument, with dark pixels being deeply engraved and white pixels remaining as topographic relief. The key considerations in the manufacture are:

- i) the physical size of the output model, which controls the size of pixels and therefore the texture they create,
- ii) how data amplitudes are converted to cut depth, ultimately controlling the elevation difference between the shallowest and deepest cuts, and
- iii) the resolution of the greyscale colourmap, which controls the smoothness of texture within the model.

Through consultation with a visually-impaired user, we determined that an A4 size print (~ 30 x 20 cm) would be appropriate. Initial trials suggested that this would be large enough for features of interest to be resolved through touch, and small enough to allow handling and reorientation by a user during exploration (Lawson and Bracken, 2011). Repeating the cutting operation twice gave a maximum relief of ~3 mm in the models, resolvable in principle by the human finger (Wheat et al., 1995) but smooth enough to prevent the texture being dominated by local peaks: however, care is needed to ensure precise consistency between the two cuts. After trials with differently discretised greyscale colourmaps, we selected one that preserved three amplitude levels. User guidance also highlighted the need for an embossed data frame and distance scales.

We chose to manufacture ‘perfectly imperfect’ prototypes: that is to say, tactile models that present the main features of interest, but that also preserve other arrivals and background noise. As such, users are able to appreciate the complexity of the full GPR dataset, including the fact that features of interest can be obscure. However, to support the full understanding of the dataset, we also produced a simple reference model that summarises the main archaeological features.

Three representations of a timeslice from the Elsecar dataset are shown in Figure 2:

- 2a shows the reference slice, highlighting the key features to provide initial orientation to a user,
- 2b shows the greyscale image supplied to the laser cutter, with the 20 ns (~ 80 cm) timeslice expressed on a greyscale colourmap with 3 amplitude level, and
- 2c shows the tactile prototype, laser cut into plywood (~30 cm wide).

Further workshops with user groups will enhance model design. While plywood provides an inexpensive print material for initial prototyping, its grain and consistency adds ‘fake texture’ into the models, and it is prone to damage. Clear acrylic is therefore likely preferable, being both smooth and more durable; furthermore, through backlighting, the acrylic model could be colour-scaled to benefit data appreciation for a broader range of both visually impaired and non-impaired users.

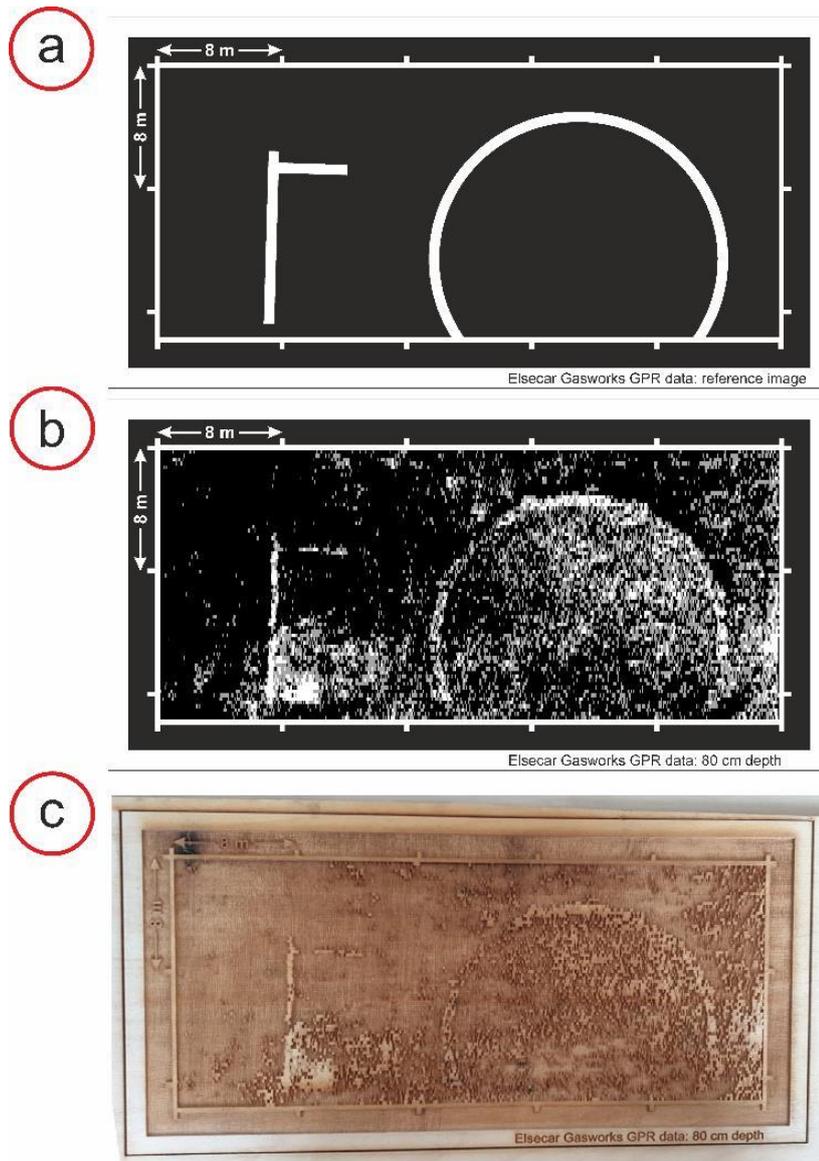


Figure 2. Representations of Elsecar GPR data. a) Simplified reference model. b) 3-level greyscale timeslice, including frame and annotation. c) Textural model of (b), laser-cut into plywood. Model is ~30 cm wide.

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## HYDROLOGICAL ASSESSMENT OF QUARRENDON LEAS ELIZABETHAN WATER GARDENS WITH A PORTABLE TIME DOMAIN ELECTROMAGNETIC SYSTEM

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The Scheduled Monument of Quarrendon Leas is located north-west of Aylesbury, Buckinghamshire, c.2.5km from the town centre and adjacent to modern housing developments; Berryfields and Buckingham Park. The site extends over c.80ha. The site comprises a mixture of grassland, hedges, trees and waterbodies. It is bounded on its east, west and north side by pasture fields, and the River Thames forms southern boundary of the site. The Quarrendon Leas Scheduled Monument is noted for the substantial network of earthworks from two deserted medieval settlements (Quarrendon Leas 1 and 2) (HER0056000000/0055700000), the ruined church of St. Peter (HER0055500000), a now demolished Tudor Manor House and moat (HER0055600000/0040700000), along with uniquely preserved water gardens (HER0055601002).

The Manor House itself is thought to have been an extravagant building built by Sir Robert Lee and subsequently owned by Sir Henry Lee (Queen Elizabeth's Champion and initiator of the Accession Day Tilts) in the late 16th century (Faulkner 2008, 1), with landscaped water gardens fit to host Queen Elizabeth I in 1592. There is, however, no evidence she visited (Faulkner 2008, 1).

The site sits on the river Thames flood plain and consequently is commonly waterlogged and supports flood meadow fauna and flora (Figure 1).



*Figure 1: Picture depicting the standing water within the remains of the water garden earthworks*

For the past ten years the site has been managed by the Buckinghamshire Conservation Trust (BCT), formed by various partners including the Buckinghamshire Archaeology Society (BAS) and Buckinghamshire Council (BC). BCT maintains the site and develops programs to make the site more accessible to the public.

The Aylesbury Development Program has seen the town expand to the north-west broadly surrounding Quarrendon Leas. The site of Quarrendon Leas provides open green space for the local community for exercise and leisure, as well as forming part of Buckinghamshire Greenway from Waddesdon to Wendover. The trail route aims to connect people and communities across the county. Buckinghamshire Conservation Trust (BCT) recognises the role Quarrendon Leas can play in

Buckinghamshire Green Infrastructure Strategy and the import contribution the archaeology and ecology adds to the project.



Figure 2: Survey Area 1 is where the Tudor Manor house is believed to be located. Five profiles were recorded with the Loupe TEM system over the earthworks forming the water gardens.

In the summer of the 2022 the Young Archaeologist Club, Aylesbury branch, with support from Geomatrix Earth Science Ltd undertook various geophysical surveys to detect remains of the Tudor manor house. In addition, resistivity profiles were measured using a portable Time Domain Electromagnet instrument manufactured by Loupe Geophysics. Unlike traditional Time Domain EM systems, the Loupe is designed to be used for near surface continuous data acquisition. The 100ATm2 Transmitter moment and 100kHz bandwidth three component receiver coils permit prospection up to a depth of around 25m. Configured as a Slingram, the transmitter and receiver were separated by a distance of 10m (Street & Duncan 2021).

The series of geospatially located profiles were collected across the earthworks which form the water gardens to the west of the location where the Tudor manor house is believed to be located (Figure 2). To date only a handful of profiles have been collected as part of a pilot study to evaluate the performance of the Loupe system for this application.

The initial results are promising with the inverted resistivity profiles providing additional insight into how effective the remaining earthworks manage drainage within this small area of the scheduled monument. Through extending the coverage of the survey, and repeating the survey during the winter months, the aim is to be able to assist BCT develop a long-term strategic plan for the hydrological management of the site.

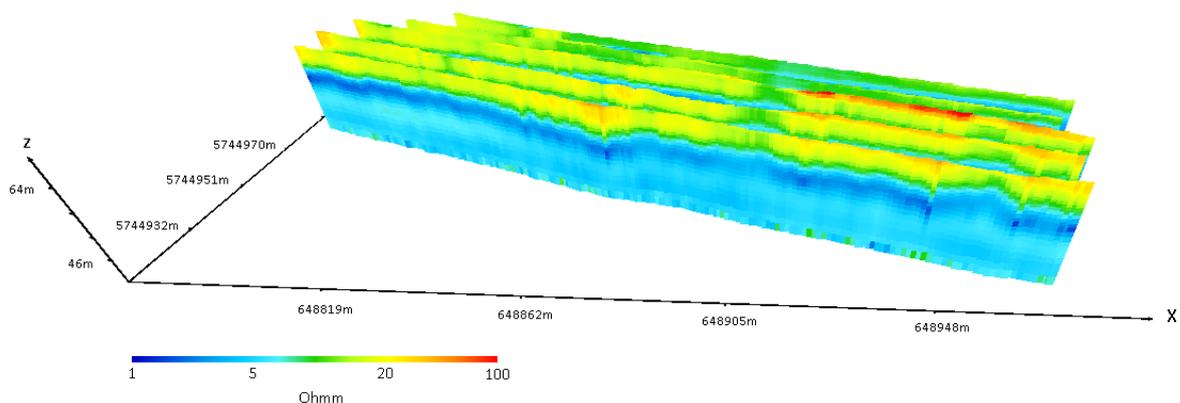


Figure 3: Inverted Resistivity profiles from the Loupe Time Domain EM system

We would like to acknowledge the Buckinghamshire Conservation Trust (BCT) for their assistance and Historic England for approval of the Scheduled Monument Consent. We would also like to thank the members of the Young Archaeology Club, Aylesbury branch, for their assistance in the data acquisition.

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Figure 1: Picture supplied by MDS-Paris

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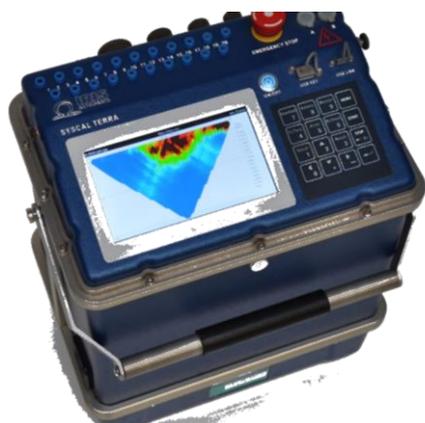
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### Ground Penetrating Radar

In 2021 we became agents for ImpulseRadar and since then have incorporated many of their CrossOver and Raptor GPR systems into the rental pool. Please contact us for further information or to arrange a demonstration.



Fig 2. - The upper image shows the raptor cart 450MHz system (left) and a fully processed dataset generated in the condor software (Right). The results identify a number buried utilities as well as an infilled basement (the high amplitude rectangular response in the North East of the dataset) from a demolished commercial property. The property is present on a map of the market square dating from 1779.



### Resistivity Imaging Systems

This Autumn we have added the new Syscal Terra Switch 72 from Iris instruments to the rental pool. The Syscal Terra offers a host of new features including full waveform recording and on-time IP measurements, as well as incorporating a modern user interface. The most significant development the Terra offers is a new master slave mode which allows multiple Terra to work together for creating large 2D or 3D datasets.

Over the last 26 years Headland Archaeology has grown to become one of the largest archaeological contractors in the United Kingdom with many years of experience in the design, management and completion of complex and challenging archaeological projects. A geophysical survey hub was established in Leeds during 2015. To provide this service Headland has recruited a core team of archaeological geophysicists who have more than 40 years' experience of carrying out geophysical surveys in the United Kingdom and Ireland. Since May 2015 Headland have carried out surveys covering in excess of 17,500 hectares for housing developments, road schemes, nuclear facilities, major infrastructure, wind and solar farm developments. The range and length of experience of our staff is critical having worked on all types of sites throughout the United Kingdom and Ireland. We can advise on the most effective techniques and methodologies to evaluate a site. Our experience is founded on comparing excavation results with survey data, something many survey companies fail to achieve, and we insist that all excavation reports include a paragraph assessing the geophysical survey interpretations against the physical evidence. We believe this approach is more likely to reduce the scale of follow-on fieldwork.

Headland recognises that each site is unique, and that soils, geology, topography and recent land use all impact on the quality and interpretability of the data. All these and other local factors are assessed to provide as accurate an interpretation of the data as possible.

The senior staff at Headland Archaeology have considerable knowledge and experience of undertaking and reporting geophysical surveys in the UK having undertaken 1000's of hectares of surveys in this area over the last 25 years'.

Headland offers a range of remote-survey services equipment and has experience of operating less frequently used equipment such as electro-magnetic conductivity meters, as well as more conventional equipment such as fluxgate magnetometers, earth resistance meters and ground penetrating radar. If we cannot offer a service inhouse, we seek out the experience and specialist geophysics company, RSK Geophysics, whom we work with regularly major infrastructure schemes.

We believe the key to a successful project outcome for the client is the speed at which the survey data is processed and interpreted, and the need for any further archaeological work established. To ensure this speed is maximised, we process the data on a daily basis, we provide advice during the works on any significant archaeology as it emerges and we produce interim interpretation plots promptly. We believe that this ongoing feedback and speed of delivery is essential to providing the client with an early assessment of the likely scope of any further archaeological works.

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## MALÅ

MALÅ grew out of the Swedish Geological Unit, who introduced the first electromagnetic loop system for ore detection. MALÅ has come a long way since then and now the range of products runs from 25MHz unshielded antennas for landscape-scale studies, through versatile single and multi-channel shielded systems up to high frequency (up to 2.3GHz) handheld antennas for investigation of buildings and individual features.



Figure 1: MALÅ MIRA HDR multichannel 3D GPR array

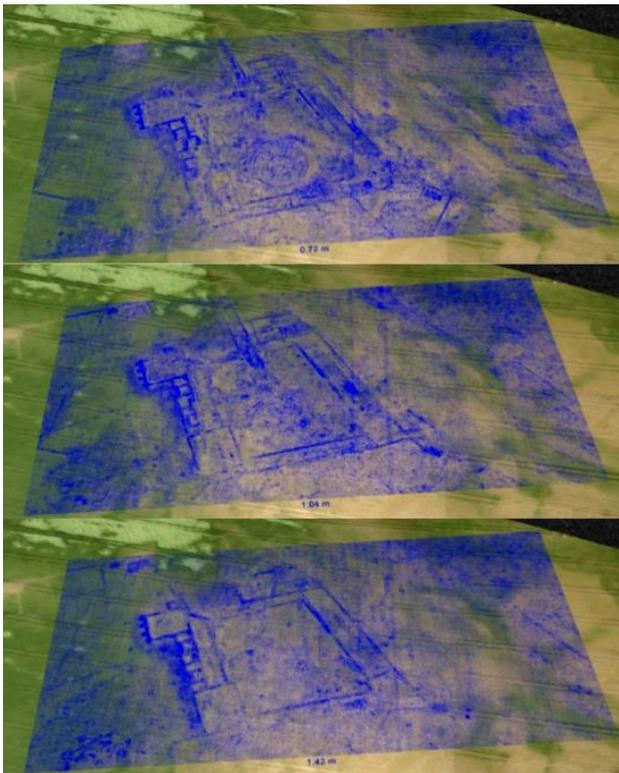


Figure 2: MALÅ GPR data from over a Gladiator training camp (courtesy of Ludwig Boltzmann Institute).

MALÅ has supported a number of high-profile archaeological institutions including the Ludwig Boltzmann Institute, the University of Bradford, Channel 4's Time Team and is also a trusted partner to numerous commercial operators.

The introduction of HDR (High Dynamic Range) antennas in early 2014 delivered significant improvements in both penetration and resolution over their forerunners. In fact, the improvement in performance is such that, in side-by-side comparisons, the HDR antennas challenge the output of more expensive dual frequency systems.

This improvement in resolution and penetration means that the MALÅ Easy Locator Pro HDR (450Mhz) is now not simply a tool for utility mapping but an attractive and capable entry-level instrument for many archaeological groups.

## ABEM

Formed in 1923, ABEM has an unparalleled history of geophysical equipment manufacture. The product range comprises electrical resistivity, seismic and time-domain electromagnetic instruments. All systems are stand-alone units with large daylight visible colour screens and no requirement for an external PC. Impressive ingress protection ratings, even during data collection, intuitive user-interfaces, on-board GPS and market-leading specifications make the range ideal for commercial, research and teaching purposes.



Figure 3: ABEM Terraloc Pro seismograph mapping upland peat deposits.

The latest incarnation of the Terrameter LS resistivity meter, released in autumn 2016, has added an innovative licensing system to what was already a powerful yet compact survey tool. This offers customers the option to buy a cost-effective entry-level instrument which can be upgraded to a full-functioning sophisticated system (or any stage between) through a simple product code update, either online or via USB. Upgrades can be permanent or time-limited if the extra capabilities are required only for a specific project. Early next year will see the implementation of 3G connectivity and an innovative 100% duty cycle method of Induced Polarisation survey (there is no 'current off' time in the measurement cycle) thereby greatly increasing the speed at which IP data can be collected.

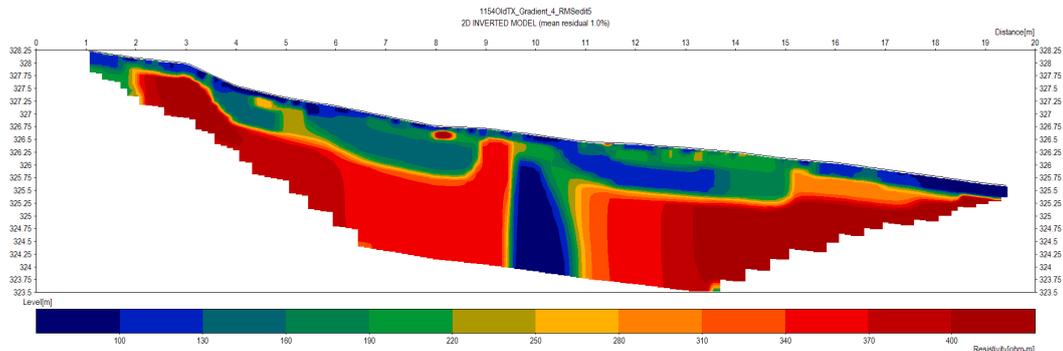


Figure 4: ABEM Terrameter LS resistivity survey over the site of historical mining works.

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SENSYS is a manufacturer of sensors and survey systems in order measure magnetic fields an anomaly. Our main sensor is the Fluxgate Magnetometer; besides we also produce Time Domain Electromagnetic coil systems.

Besides our base philosophy of always using multiple sensors for redundancy, consistency, efficiency and most coverage in each survey track, we are always eager to explore new carrier platforms to disrupt state-of-the-art methods.

### Drone based magnetics for archaeological prospection

Saying that, the Bavarian State Department of Monuments and Sites, Archaeological Prospection, Munich, Germany together with the Ludwig Maximilians University, Department for Earth and Environmental Sciences, Section for Geophysics, Munich, Germany inquired us to support on a [Large-scale UAV magnetometry on a former World War II airfield at Ganacker \(Lower Bavaria, Germany\)](#) searching for airplane wracks. Besides some early testing in the UK with Jonathan Brindley from JBUAS, this was one of the first large scale surveys to find out whether drone based magnetometry can play a valid role in archaeology.

### Setup

On the 110ha agricultural area we were using our MagDrone R4 with five triaxial Fluxgate sensors with +/-75,000nT each. The sensors were spread over 200cm, giving a sensor spacing of 50cm each. The R4 was mounted on a DJI M300, controlled by the SPH SkyHub for close ground flight and direct GPS output into our data acquisition unit.

MagDrone R4 read-out unit

DJI MATRICE 300 RTK



FGM3D/75 fluxgates

Figure 1: SENSYS MagDrone R4 on DJI M300

### Autonomous drone flight

With smooth conditions on-site, the drone flight path was pre-configured for an autonomous flight. That way we scanned the area within 4 days, achieving constantly 30ha a day, flying 1 meter above ground with 5 seconds per meter.

## Results

Besides different expected but as well as unexpected findings like structures of a former rifle shooting range, basements of aircraft shelters and some other extending anomalies, the archaeologists especially valued the consistency of data generation, the noise floor and data density.

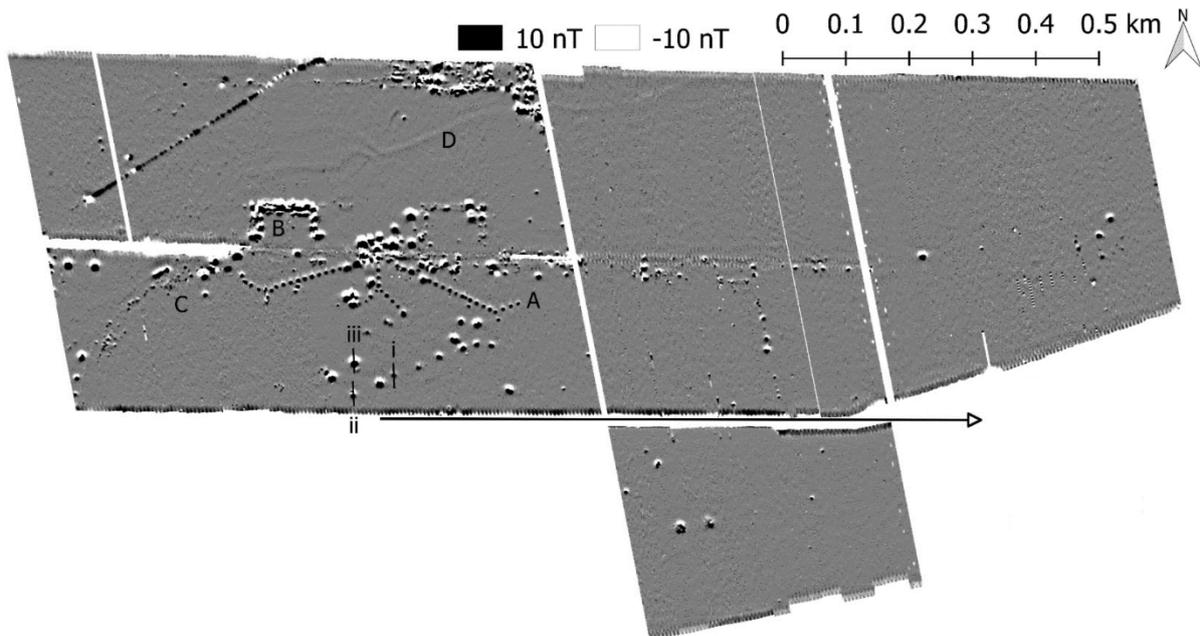


Figure 2: Results of the UAV magnetometry in Ganacker with marked detail sections and individual anomalies discussed below. Magnetogram: dynamic +/- 10 nT; black = positive; white = negative; spatial resolution 0.2 m

A paper was published (and references in the bibliography) to sum up first results. Meanwhile, another part in that surrounding was surveyed with the drone and directly compared to existing measurement with the SENSYS push-cart system MXPDA. The most challenging aspect of using the drone is not so much the noise floor (of the electrical drone and relative movements), but the higher distance of sensors to the ground that you need to keep for safety reasons (of the drone). This will cut off an important part of magnetic readings and might prevent the analysis of +/-1nT magnetic maps – at the moment.

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