Recent Advances in Archaeological Geophysics

The Geological Society
Burlington House, Piccadilly,
London W1J 0BG

Tuesday 3rd December 2024

Contents

NSGG
Near-Surface Geophysics Group

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Programme

Lecture Programme:

0930-1000	**Registration and Coffee**
1000-1005	**Introduction**
1005-1020	*From an empty field to the scheduled monument – The role of modern geophysics in the planning system.* A Chmielowska, V Oleksy and J Lawton
1025-1040	*Wroxeter Roman City and the Attingham Estate: expanding geophysical horizons in a Romano-British landscape.* P Johnson and C Harris
1045-1100	*The role of geophysical survey as an archaeological evaluation technique on large scale solar schemes.* A James
1105-1120	*High Resolution UXO Magnetometry over the Dogger Bank.* B Urmston, V Gaffney and C Gaffney
	Tea/Coffee break
1150-1205	*Multi-disciplinary site investigations of WW2 ‘British Resistance’ operational bases (OBs) in the UK.* J Pringle, K Wisniewski, P Doyle, W Ward, I Stimpson, L Hobson, S Carr, C Kyriakou, R Green and N Hannaford.
1210-1225	*I see dead people: 3D ground penetrating radar survey for imaging unmarked graves, clandestine and mass burials.* M Pisz, C Gaffney, D Taylor, J Moore, S Różycki, A Hegyi, R Mieszkowski and S Kowalczyk
1230-1245	*Archaeological geophysics and the Shubenacadie Indian Residential School search.* J Fowler, R Knockwood and R Lewis
1250-1305	*The ghostly features of Odberg: Studying post-depositional changes in GPR data.* P Schneidhofer, R Cannell, E Nau and C Tonning

1310-1410	**Lunch (Lower Library)**
1320-1400	**NSGG AGM (Lecture Theatre)** – all welcome
1410-1425	*Small change, big consequence: Extended landing gear provides high-quality drone-based magnetic data.* A Stele, C Seisenbacher, L Kaub, G Häußler and R Linck
1430-1445	*Validating broadband multispectral vegetation indices to remotely detect shallow subsurface anomalies in temperate, vegetated terrain.* A Morley, T Mather, D Pyle and J M Kendall
1450-1505	*A pilgrim's journey: Gradiometer and LiDAR surveys of two islands of ecclesiastical significance on Lower Lough Erne, Enniskillen, County Fermanagh, Northern Ireland.* K Colman, P Edwards, L Jones and A Russell
1510-1525	*New geophysical surveys along the course of the Dorchester Roman Aqueduct.* H Manley and N Crabb
1530-1545	*Revival of geophysical measurements in Ashur (Iraq).* J Fassbinder and M Wolf
	Tea/Coffee break
1615-1630	*Interactive, shallow machine learning-based semantic segmentation of geophysical data from archaeological sites.* L Verdonck, M Dabas and M Bui
1635-1650	*GPR survey provides evidence for a bricked cellar underneath a Baroque garden pavilion at Memmingen (Bavaria)* R Linck & A Stele
1655-1710	*Getting under the skin of the serpent's tail: Imaging the buried stones and stone holes/pits of the Beckhampton Avenue, Avebury.* P Cheetham, M Gillings and J Lewis
1715-1730	*Heading West from Vester Vandet? Interpreting the traces of a Viking-age and high-medieval site in North-Western Denmark.* A Stamnes, A Møller, T Christiansen and M Jessen
1745-1900	**ISAP AGM (Lecture Theatre)**

FROM AN EMPTY FIELD TO THE SCEDULED MONUMENT – THE ROLE OF MODERN GEOPHYSICS IN PLANNING SYSTEM.

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The evolution of geophysical techniques over recent years has markedly transformed archaeological practices, as demonstrated by a recent gradiometer survey conducted in Cambridgeshire. Initially designed as a routine, standard commercial investigation, this survey unexpectedly revealed a significant Romano-British settlement complex within just one day of data collection. Spanning approximately 31 hectares, the complex displayed a well-defined settlement structure, including a network of roads and a potential central square.

This discovery prompted a re-examination of the project within the planning process, catalysing a series of discussions and collaborations among stakeholders, including local authorities, archaeologists, and developers. The geophysical findings were pivotal in these dialogues, illustrating the capacity of non-invasive methodologies to influence heritage management practices.

This case exemplifies a successful integration of geophysical survey results into development design, culminating in the settlement's formal designation as a Scheduled Monument. This highlights the potential of modern geophysical methods to identify and protect previously unknown archaeological sites with minimal excavation.

Furthermore, this example underscores the importance of interdisciplinary collaboration to address the complexities in light of new archaeological evidence. The project demonstrates how contemporary geophysical technologies can inform heritage preservation strategies, ensuring a balance between archaeological integrity and developmental considerations. This paper will explore the implications of such findings for future projects going through the planning process and the role of advanced geophysical methods in enhancing our understanding of archaeological landscapes.

WROXETER ROMAN CITY AND THE ATTINGHAM ESTATE: EXPANDING GEOPHYSICAL HORIZONS IN A ROMANO-BRITISH LANDSCAPE.

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Introduction

As part of the National Trust's bold 2030 vision to establish c. 200ha of new woodland at their Attingham Estate in Shropshire, they commissioned Magnitude Surveys to undertake a c. 1000ha magnetometer survey across the Estate's landscape. This survey, combined with other desk-based sources, will be used by the Trust to manage archaeological risk for the 2030 vision, as well help them understand, protect, or manage their heritage assets—particularly as previous archaeological investigations revealed certain areas of the Estate as being more susceptible to the loss or impact to the archaeological record through agricultural use.

The Attingham Estate is situated within a rich archaeological landscape. Evidence across the estate suggests there has been continuous occupation of the area since at least the Bronze Age and parts of Wroxeter Roman City (Viriconium Cornoviorum) lie within the Estate. The City itself was subjected to extensive geophysical survey during the 1990s and was one of the first Roman cities to be comprehensively studied using geophysical techniques.

Magnitude Surveys' recent landscape-scale magnetometer survey has revealed features and sites from the early Prehistoric to modern periods, which enable us to properly contextualise the understanding of urban Wroxeter derived from those earlier surveys within its immediate hinterland.

The importance of research questions that incorporate the hinterlands of urban settlements as well as the urban areas themselves has long been argued as crucial for fully understanding their role as, and within wider socio-cultural and economic landscapes (e.g. Johnson 2013: 8–23).

The survey undertaken at the Attingham Estate offers an almost unique possibility to study an extensive peri-urban landscape in detail and at high resolution. In addition to covering large parts of the immediate northern hinterland of the city, our survey was able to re-collect data across the northernmost part of the intra-mural area, leading to new insights and a re-evaluation of the development of the city from its foundation to abandonment.

In addition to addressing questions about the development of Wroxeter and its hinterland, the survey at Attingham enabled us to assess different methodological approaches to achieving the effective coverage and assessment of this unquestionably large area within the constraints of a development-led project. As current guidelines largely pre-date the widespread use of GNSS positioned, and cart-based multi-sensor arrays the outcomes of these surveys may offer suggestions for effective future strategies.

This paper will summarise the highlights of our survey as they relate to the development of the hinterland of Wroxeter, and address key methodological issues surrounding the use of large-scale magnetometry to assess the archaeological potential of extensive landscapes.

THE ROLE OF GEOPHYSICAL SURVEY AS AN ARCHAEOLOGICAL EVALUATION TECHNIQUE ON LARGE SCALE SOLAR SCHEMES.

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Solar schemes offer the archaeological community a rare opportunity to enhance our knowledge of the archaeological record, while also providing a mechanism to preserve and protect rural archaeological sites from the current damage that is occurring from agricultural activity.

The number of large-scale solar schemes has dramatically increased over the last decade, and since 2018 there has been an emergence of solar-based nationally significant infrastructure projects (NSIP), which cover 100s of hectares of land.

As detailed in the National Policy Statement for Renewable Energy Infrastructure (NPS EN-3 paragraph 2.10.109), below ground impacts caused by solar panels are generally limited. In a recent position statement produced by Solar Energy UK, the impact of solar panels was estimated to comprise 0.06% of the area they are proposed to be located within. It is also noted in NPS EN-3 that solar developments may have a positive effect on archaeological assets, as they are removed from regular ploughing (paragraph 2.10.110).

Despite the usefulness of geophysical surveys in providing the information required to identify archaeological sites, there is often a requirement to undertake excessive intrusive pre-determination evaluation works to test the ‘success’ of the geophysical survey. There is no guidance to what constitutes a proportionate archaeological evaluation and no standard approach across the UK. The Chartered Institute for Archaeologists (CIfA) state in their Universal Guidance for Archaeological Field Evaluation:

*“Wherever possible, non-intrusive methods **should** be considered as the first option, with intrusive techniques used only where necessary to achieve the purpose of the archaeological field evaluation.”*

Using the recently consented Cottam Solar Project as a case study, this paper looks to explore the role of geophysical survey as an archaeological evaluation technique for large scale solar schemes.

Cottam Solar Project

The Cottam Solar project comprises c.1292 ha of land spread across four sites joined by a cable corridor in the west of Lincolnshire, along with a cable corridor proposed to be shared with other nearby schemes that spans c.158 ha across Lincolnshire and Nottinghamshire. This case study will primarily focus on the land solely within the Cottam Scheme.

Figure 1: Extract of gradiometer data collected as part of the Cottam Solar Project. In the foreground are anomalies associated with a shrunken medieval settlement and enclosures of possible late prehistoric to Roman date.

While desk-based research identified areas with an archaeological potential within the Scheme, magnetic geophysical survey undertaken between July 2021 and November 2022 proved critical in identifying previously unrecorded sites within the scheme. Numerous clear concentrations of magnetic anomalies were detected that were indicative of prehistoric, Roman settlement, early medieval and medieval activity. It also indicated the extent of destruction caused by agricultural activity, mapping ridge and furrow, former field boundaries, land drains and ploughing.

Repeatability tests were used to scrutinise collected data and were considered to demonstrate the geophysical survey technique chosen for the Scheme had provided meaningful data and that a high level of data integrity was achieved.

Concentrations of anomalies interpreted to be of an archaeological origin were tested by trial trench evaluation between June and November 2022. The trial trench evaluation confirmed the extent and nature of archaeological deposits identified through the geophysical survey. It was noted during the trial trench evaluation that anomalies with good patterning and increases in magnetic value correlated with well-defined features; those with weak increases in magnetic value or informal patterning corresponded with shallow ephemeral features. Magnetic anomalies of an unknown origin were tested in several areas, and were proven to be caused by features of an agricultural and geological origin. Negligible or isolated archaeological features were identified in ‘blank’ areas where geophysical survey had suggested there was a low potential for buried remains to be present. Where isolated features were present, these were ephemeral and often lacked dating material to confirm an archaeological origin. Consequently, it was considered that there was limited potential for extensive archaeological remains to be present that had not been detected geophysical survey, and no justification for excessive evaluation trenching in ‘blank’ areas where no potential for archaeological remains had been identified by non-intrusive evaluation.

Despite this evidence the local planning authority required a high sample of trenching to be undertaken across all areas within the Scheme prior to the application.

The Cottam Scheme was subject to a period of examination by the Planning Inspectorate between 2023 and 2024, during which time what constitutes a sufficient level of archaeological evaluation was debated in great detail.

The Planning Inspectorate released their recommendation report In June 2024, which states that a low sample (1.09%) of trenching in blank areas post-determination was sufficient to confirm the results of the non-intrusive evaluation. The requested high sample of blanket trenching requested by the LPA was not required to support the application.

A programme of post-determination trenching is currently in discussion.

Discussion

Large scale solar schemes offer a vital opportunity to use archaeological evaluation techniques to discover new sites and preserve them for future generations. This is demonstrated by the Cottam Scheme, where magnetic geophysical survey, supported by the results of targeted evaluation trial trenching, has identified numerous previously unrecorded archaeological sites that are at risk from destruction from agricultural activity.

However, despite the effectiveness of geophysical survey on the Cottam Scheme, a disproportionately high level of intrusive archaeological works was required, as the results of the geophysical survey were not considered sufficient in isolation by the LPA to support the planning application.

A large part of the issues that arise is the lack of guidance on what constitutes a proportionate evaluation. There is no standard approach to the scope and extent of archaeological evaluation for low impact schemes, such as solar, within the UK and huge inconsistencies in the way that different LPAs are interpreting policy and guidance. In some regions, as demonstrated by the Cottam Scheme, there are requirements for high samples of predetermination trenching, while in other areas minimal trenching is required where geophysical survey is deemed to have provided sufficient information.

Ultimately, and in line with CIfA guidance for a field evaluation, what can the geophysics community do to help promote the validity of non-intrusive evaluation techniques as the first option, with intrusive techniques used only where necessary in a staged, informed and targeted approach, to achieve the purpose of the field evaluation?

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HIGH-RESOLUTION UXO MAGNETOMETRY OVER THE DOGGER BANK

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At the Last Glacial Maximum, sea levels were approximately 120m lower than the present day, exposing a vast area of seabed now commonly known as Doggerland. Lying to the east of the British Isles and approximately centred upon the shallowest part of the expanse between the British Isles and mainland Europe, it has become the focus of the current acceleration of renewable energy infrastructure due to the relative accessibility for monopile turbines and future floating wind installations.

For several decades, archaeological prospection over the submerged landscapes of the southern North Sea has primarily concentrated upon the analysis of marine geophysical survey data typically collected during prospection for oil, gas and mineral extraction opportunities. The repurposing of these datasets for archaeological prospection has allowed the identification and understanding of large-scale landscape and geological features across the southern North Sea.

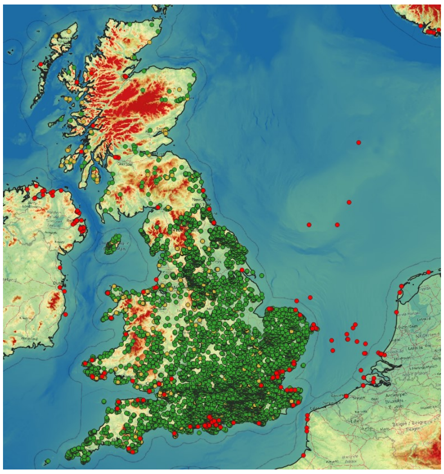

Figure 1: Known terrestrial records across Britain (green) and known marine records (red). Data from EUDEM, EMODNET & SPLASHCOS

Datasets provided by Royal HaskoningDHV over one of the Dogger Bank wind farms, which is one of many currently coming online, have demonstrated that magnetometry has an important role in the understanding of near-surface sedimentology and archaeology. Previously such data were collected at 50m resolution but the requirement to 'derisk' future development of windfarms has necessitated collection of magnetometer datasets at <2m resolution.

It is notable that the Late Upper Palaeolithic & Mesolithic periods are not often targeted by terrestrial geophysical surveys, largely due to the ephemeral nature of the contemporaneous features. However, with sites exhibiting monumental archaeological features such as Warren Field in Aberdeenshire, Houghton Regis in Bedfordshire, and the Stonehenge landscape in Wiltshire, it is possible that serendipitous large-scale surveys will cover the locations of these otherwise undiscovered sites. The high-resolution magnetometry dataset from Dogger Bank A alone covers some 42 sq. km, and covers both near-shore and now the deeper waters over what would be a terrestrial post-glacial landscape. Records of contemporaneous human activity demonstrably indicate that there should be considerable material remaining in this landscape, and it is assumed that there will be attendant detectable features; given that the final submergence of the Doggerland archipelago occurred some 8,000 years ago, it also presents a palimpsest with little in the way of later agriculture, urbanisation & modification seen elsewhere in the British Isles & mainland Europe.

This short presentation will discuss the utility of magnetometry in the terrestrial and offshore sectors. Terrestrial comparators suggest that the Late Upper Palaeolithic and early Mesolithic, and the late Pleistocene/Holocene transition, are poorly represented within magnetometer datasets in comparison with the better-known seismic interpretations from the same location. Evaluation of existing datasets collected for non-archaeological investigations has, and will be, crucial to our understanding of the submerged landscapes of the southern North Sea, with the potential to reveal human-scale features for the first time.

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MULTI-DISCIPLINARY SITE INVESTIGATIONS OF WW2 ‘BRITISH RESISTANCE’ OPERATIONAL BASES (OBs) IN THE UK

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Introduction

In 1940, with the fall of France imminent, Britain prepared for invasion. After Dunkirk, with most armour and transport lost, defensive plans included coastal defences and inland ‘stop line’ (GHQ Line) to slow the invader to allow remaining forces to engage (Fig.1). Local Defence Volunteers (later Home Guard) were raised to buy time for the Home Army to deploy. Secret ‘Auxiliary Units’ were also formed, tasked with guerrilla activities in the invading Germany army’s rear. 4-8 patrol men were highly skilled, often gamekeepers and poachers, with expert local area knowledge, with below-ground Operational Bases (OBs) in remote locations to avoid detection. No official records are released; but OBs were ‘Mark I’, enlarged deer setts, smuggler caves, etc., and Mark II, prefabricated designs by the Royal Engineers. This presentation details innovative research collaboration between academics and CART volunteers to investigate and map these UK-wide.

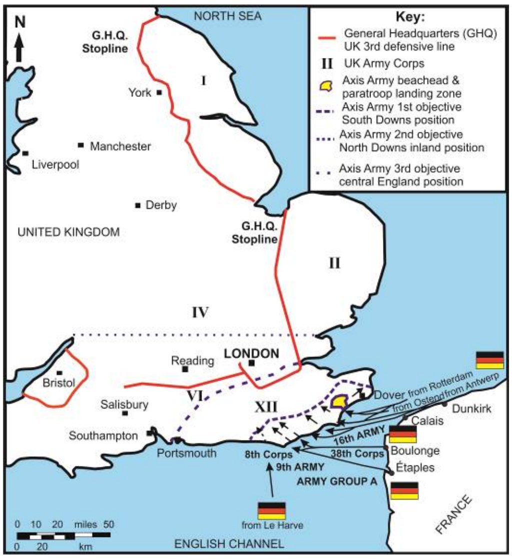

Figure 1: 1940 map showing UK defence ‘GHQ’ lines and German objectives (Carr et al. 2020).

Site Investigations

The CART team, comprising of interested local volunteers spread throughout the country, have been documenting the remaining conflict archaeology for over 20 years (see CART website link).

More recently, academics have also become involved. For those sites which have shown promise, a series of different site investigations have been undertaken through the last 5 years, deliberately choosing sites in different

Figure 2: Electrical Resistivity Imaging (ERI) data over a WW2 OB in Wiltshire, UK

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areas of the country, with different bedrock/soil types and depositional environments to determine if they can be geophysically detected and characterised (Fig. 2). This follows on from research on detection and characterisation of WW2 air-raid shelters (Ainsworth et al. 2018).

A successful #Digital8 Heritage Lottery fund (HLF) grant in 2022 has further allowed the research team to digitally record 80 (so far) remaining relict WW2 heritage sites related to these UK wartime activities, including 360° virtual tours of underground Operational Bases, the Coleshill House estate HQ training areas in Wiltshire, relevant resistance museums (e.g. Parham, Suffolk) and other areas of interest – see Fig.1 and the CART website for details.

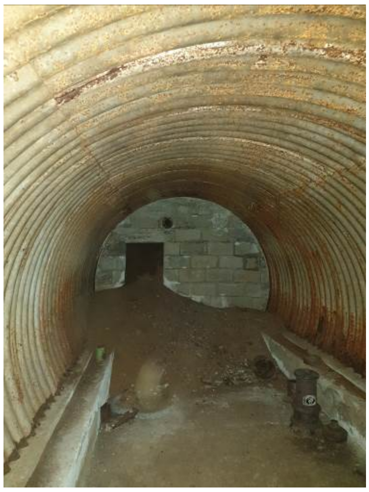

Figure 3: Photograph of WW2 underground Operational Base in Suffolk, UK)

The relict archaeological sites are in all sorts of condition, from those which are almost completely intact with ventilation pipes, entry/emergency exit shafts in good condition (Fig.3) to those which have been destroyed/filled in or where there no remains at all. The Carr et al. (2020) paper details a study of 3 sites in Suffolk, varying from almost complete preservation with intact materials still present to those completely destroyed.

Future Research

Further work will continue to add details of both undiscovered and digitally recorded conflict archaeology sites across the UK in this area. It is hoped that this continuing research will highlight these secret activities in this crucial period of World History and the importance of involving local interested volunteers.

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I SEE DEAD PEOPLE: 3D GROUND PENETRATING RADAR SURVEY FOR IMAGING UNMARKED GRAVES, CLANDESTINE AND MASS BURIALS.

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Unmarked graves and clandestine burials are common targets for geophysical surveys worldwide (Barone et al., 2022; Molina et al., 2024). Their location could be of interest to law enforcement, heritage managers or indigenous communities. Arguably, the most effective method for the detection of these types of targets is Ground Penetrating Radar (GPR).
One of the major advancements in GPR technology was the implementation of multi-channel arrays, commonly referred to as 3D GPR, offering a high horizontal sampling resolution and high area coverage efficiency, especially when the data is collected with a vehicle (Trinks et al., 2018).
This paper presents a selection of case studies from Poland and England, showcasing the potential and limitations of 3D GPR prospecting for detecting historical and crime-related burials. We also propose and present an innovative method of integrating and disseminating geophysical data using virtual 3D environments.

Figure 1 – Three different 3D GPR systems (from left to right): Malå MiniMIRA, ImpulseRadar Raptor 45 and Malå MIRA Compact

Instruments and software

In this paper, we present survey results acquired with three different 3D GPR systems: 8-channel ImpulseRadar (IR) Raptor45, 8-channel Malå MiniMIRA and 10-channel

Malå MIRA Compact, each offering the crossline within the swath of respectively 8, 8 and 6.5 cm (Fig. 1). The presented data was processed using SubGeo WAVE GPR software and the software packages provided by manufacturers (Condor for IR and rSlicer for Malå). To produce the 3D visualisation two open-source software packages were used: Blender 3.4 (with the BlenderGIS add-on) and QGIS were used to combine the UAV-based photogrammetry model and GPR data spatial interpretations provided in shapefile format.

Mass burials in Treblinka Nazi German extermination camp in Poland

Treblinka II was a death camp erected by Nazi Germans in occupied Poland during the second world war, in the vicinity of Treblinka I forced labour camp. The facility was focused on the systematic extermination of civilians, mostly Polish Jews, and Jews of other nationalities, Romani and Sinti. It is estimated that around 800,000 people were murdered in gas chambers and buried in mass graves on site. A complementary geophysical survey enabled the location of numerous features of that deliberately dismantled facility. The 3D GPR method proved to be particularly effective in imaging subsurface features, including mass burial pits.

Figure 2 – 3D GPR Mala MiniMIRA data processed using the SubGeo WAVE GPR software.

Unmarked graves around the All Saints' Parish Church in Ilkley, England

The non-destructive survey in Ilkley (West Yorkshire, UK) aimed to create an accurate detailed topographic and geophysical imagery of the environs of the Manor House and All Saints' Parish Church. An objective of the geophysical survey was to further investigate the known location of the Roman fort and its surroundings, particularly for the presumed Anglo-Saxon presence. In the area adjacent to the church, 3D GPR detected around 70 individual burials at different depths (Fig. 2). The high spatial resolution of the survey allowed us to recreate the distribution of burials in a 3D environment, combining photogrammetry recording of tangible heritage and hidden features. Georeferenced GPR slices were loaded into QGIS and interpreted and stored in a shapefile format using feature class, depth and thickness attributes. The burials and grave features were imported into Blender 3.4 with the georeferenced model. Depth and thickness attributes allowed for 3D modelling of the features interpreted from 3D GPR anomalies to create several visualisations of the grave features.

Jewish cemetery in Drzewica (Poland) desecrated by Nazi Germans

A Jewish cemetery in Drzewica (central Poland) was a subject of a war crime committed by Nazi Germans occupying Poland during the second world war. The graveyard was desecrated and matzevahs (tombstones) were taken away by perpetrators and used for paving sidewalks in the town. After the war, in communist-ruled Poland, the memory of that place and events faded out, also due to the extermination of the local Jewish community in Treblinka. Spatial analyses of the archival data allowed us to reconstruct the location and extent of the cemetery. Detailed 3D GPR survey allowed us to detect over 300 individual burials and more precisely delineate the extent of the former graveyard, t put the site on the list of protected monuments.

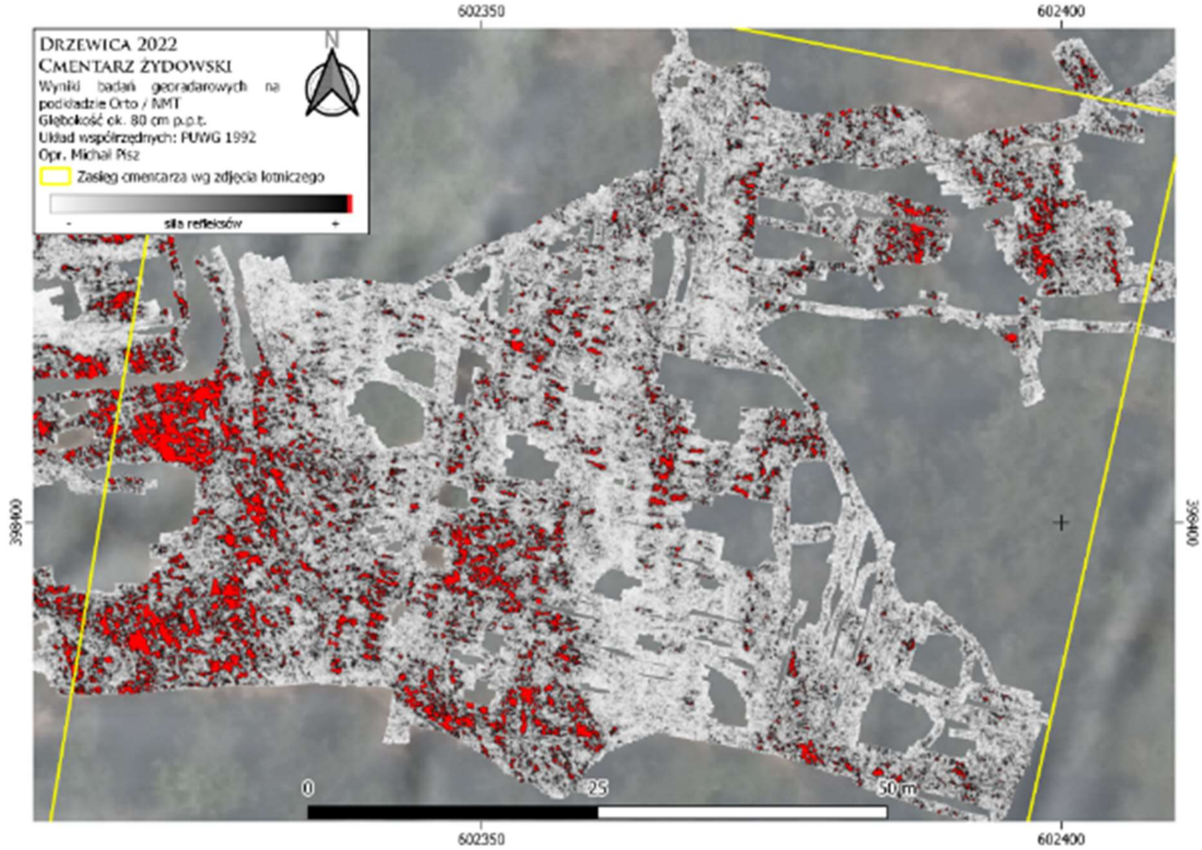

Figure 3 – Jewish cemetery. Results of the 3D GPR survey plotted on orthophoto / DEM hillshade basemap. Depth: c. 80 cm b.g.l. CRS: PUWG1992 (EPSG: 2180). Data processed with Condor software.

As this study demonstrates, the technological advancement in 3D GPR imaging pushes forward the boundaries of detection and visualisation of burials. Compared to single-channel, multi-channel GPR offers horizontal resolution up to tens of times greater, which in combination with appropriate processing workflow, could lead to the creation of very accurate records of detected graves. The use of this technique could support law enforcement with the detection of clandestine burials or tracing the evidence of old crimes. Innovative methods of multi-dimensional visualisations could be a valuable and more inclusive way of disseminating heritage data, useful for enhancing teaching and learning experience as well.

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ARCHAEOLOGICAL GEOPHYSICS AND THE SHUBENACADIE INDIAN RESIDENTIAL SCHOOL SEARCH

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In May of 2021, Canada was shaken by news that unmarked burials had been detected at a former residential school site in Kamloops, British Columbia. According to the National Centre for Truth and Reconciliation at the University of Manitoba, "…First Nations, Inuit and Métis Nation children were taken from their families and communities to attend schools which were often located far from their homes. More than 150,000 children attended Indian Residential Schools. Many never returned" (NSTR 2024a).

The abuses of the residential school system have been well-attested in recent decades, and the apparent rediscovery of graves with the aid of GPR inflamed old wounds and shocked communities, governments, and researchers into action. How many unmarked burials were there, and could they be found? These questions activated Canadian archaeologists, many of whom had been collaborating for years with Indigenous communities, to lend a hand.

Figure 1: An undated photo of the main building at the Shubenacadie Indian Residential School, with the Shubenacadie River in the foreground. SOURCE: The Chronicle Herald.

The Shubenacadie Indian Residential School is no longer standing, but it is well remembered. Academics (Thomas-Millward 1997), heritage professionals (Ouelette and Bernard 2019), popular writers (Benjamin 2014), and survivors (I. Knockwood 1992; D. Knockwood 2018) have produced valuable studies and reminiscences. The main building was constructed on a hill overlooking the Shubenacadie River, in centra Nova Scotia (Figure 1). Between 1929 and 1967, when the school finally closed, over 2,000 children attended. The National Centre for Truth and Reconciliation records the names of 17 children who died while registered at the school (NCTR 2024b), but cultural memory, in addition to describing horrible abuse, suggests many more went missing. More troublingly, stories passed down through families speak of burials on the school grounds.

We had been working collaboratively with the local Mi'kmaw community, Sipekne'katik First Nation, for over 20 years when news of the Kamloops discovery arrived. In response to requests from Chief and Council, and from the Mi'kmaw Grand Council, which represents the broader nation, we assembled a team to investigate the Shubenacadie residential school site. Our goal was to bring a landscape archaeological approach, and to employ multi-instrument geophysical surveys to examine areas community members identified as having high potential for unmarked burials.

The project was complex on many levels, not merely the technical, which is the focus of this presentation. The Mi'kmaq and their ancestors had inhabited this river valley for thousands of years before French missionaries and European farmers arrived in the 18th century, and all have contributed to a fascinating and varied archaeological record prior to the founding of the residential school. Indeed, resolving the first phase of our ongoing research depended significantly on detailed historical research as well as collating and querying cultural memory.

The residential school site has undergone complex transformations since 1967 as well. Most of the old architecture is gone and a plastics plant now stands on the ruins of the main school building. When we began work in June, 2021, new crops of hay and corn were taking root over much of the old school grounds. Consequently, the race was on to collect data before being outpaced by vegetation.

As a result of our interdisciplinary and multi-instrument approach, which included aerial photogrammetry, LiDAR, as well as terrestrial electromagnetic induction and GPR surveys, all of which was wedded to historical research and cultural memory, two likely unmarked burials were detected. However, contrary to expectation, the evidence suggests they were not related to the residential school.

Our search at the Shubenacadie Indian Residential School site was perhaps the first major research program of its kind in Canada following the Kamloops announcement. It is distinctive for the breadth of its methodology, and both the rapidity and the collaborative spirit in which it was undertaken and led. As it happens, what began as a form of geophysical archaeological 'triage', and an attempt to find answers to difficult questions, is now developing into a broader, community-led research and training program.

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THE GHOSTLY FEATURES OF ODBERG: STUDYING POST-DEPOSITIONAL CHANGES IN GPR DATA

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The site of Odberg in Larvik, southern Norway, is best known for its large assemblage of leveled grave mounds. In 2004/5, a team from the Cultural Heritage Museum Oslo (KHM) excavated several burial mounds (Martens & Ekstrøm 2007). The excavation revealed significant agricultural impact on the site and among other uncovered distinct grey and reddish layers in the ring ditch backfill, interpreted as remnants of fires from burial ceremonies.

In 2020, Odberg was selected by the VEMOP project to study the effects of environmental factors on GPR data. Motorized GPR surveys unexpectedly detected not only undisturbed burial mounds but also some of the ring ditches excavated in 2004/5, raising questions about the persistence of these features despite their removal.

During soil sensor installation for VEMOP, the backfill materials were investigated more closely and samples were collected for laboratory analysis. Results revealed signs of podzolization, a soil formation process characterized by chemical changes that result in the development of distinct horizons with variations in color and pH. A key feature is the bleached, whitish-grey E horizon, which lacks iron oxides that have become mobile and leached downward. In contrast, the Bhs horizon below is enriched with these iron oxides, giving it a reddish appearance.
Based on the combined results of the excavation, laboratory investigations and GPR survey, it became evident that the podsol at Odberg must have developed after the construction of the mounds and that it seemingly only occurs localized around them. These findings also confirmed that even though the backfill of some of the ring ditches were removed during excavation, the post-depositional changes persisted in the soil and were detected by the GPR sensors.

The poor preservation of the ring ditches suggests these features may eventually disappear entirely, while the surrounding podzolization is likely to persist longer and remain detectable in future GPR surveys. Similar conditions favorable to podzolization may be present at other sites in Lågendalen and across Norway, indicating this process is not unique to Odberg. These findings raise important questions about the heritage status of such ephemeral features and how they should be documented and differentiated from better-preserved remains.

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SMALL CHANGE, BIG CONSEQUENCE: EXTENDED LANDING GEAR PROVIDES HIGH-QUALITY DRONE-BASED MAGNETIC DATA

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Introduction

For several years, we have been working on adapting and further developing drone-based magnetometry for near-surface geophysics, with a particular focus on high-resolution archaeological prospecting. Currently, we are testing the promising Sensys's MagDrone R4. This instrument includes a Sensys data logger and a sensor frame equipped with five FGM3D/75 three-axis fluxgate sensors, along with a SkyHub on-board computer from SPH Engineering. The system is typically mounted on a DJI M350/M300 drone, with the sensor frame attached to the landing gear (Fig. 1A). However, in this configuration, the proximity of the sensors to the drone causes interference, which can be detected in the data (Stele et al., 2023).

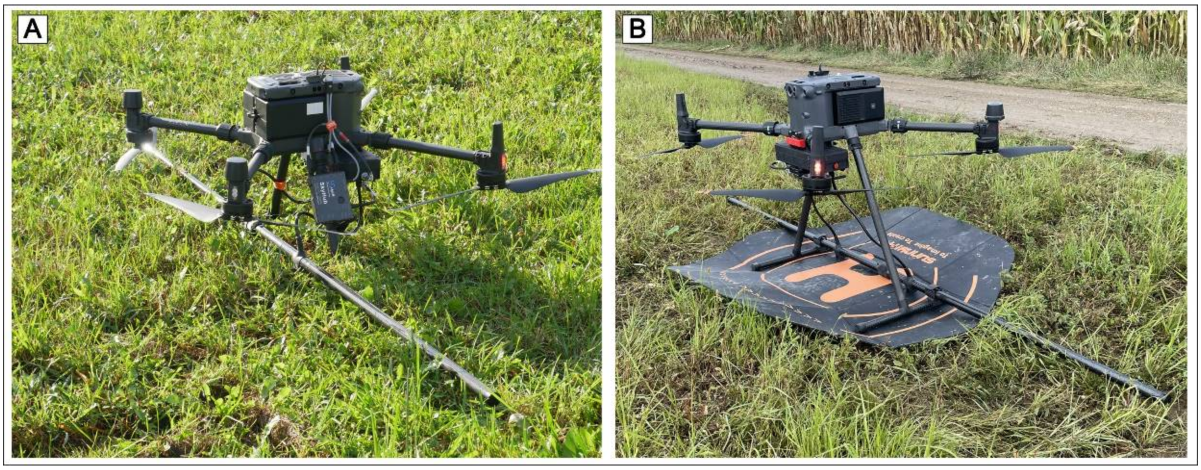

Figure 1: The Sensys MagDrone R4 instrument mounted on the DJI M350 platform with (A) standard landing gear (sensor frame – drone distance about 0.2 m; photo: A Stele) and with (B) extended landing gear (sensor frame – drone distance about 0.4 m; photo: G Häußler).

In this extended abstract, we compare the standard DJI M350 landing gear with a recently developed extended version (Fig. 1B) to assess the impact of increased distance between the sensor frame and the drone on data quality. To conduct the comparative analysis, we flew both landing gears over the same area at a height of about 0.8 m (±0.05 m) above the ground level and at a constant airspeed of approximately 3 m/s. The test site for this study is an Iron Age burial mound near Welschingen, located between Stuttgart and Lake Constance in southwestern Germany.

Magnetogram and frequency analysis

As expected from earlier tests and surveys, the third sensor, located directly underneath the drone, is especially prone to interference from the aircraft. In this case, the disturbances are so massive that data from the third sensor are unusable for archaeological interpretation (Fig. 2A). This leaves us with a gap in which valuable archaeological data can be lost. In contrast, the third sensor generates interpretable data during the flight with the extended landing gear. Not only larger structures, such as circular ditches or burial pits, can be recognised, but also smaller features (presumably small/post (?) pits) within the burial mounds (Fig. 2B). Although disturbances and slight stripes can also be recognised in the latter magnetogram, these data are more suitable for the clear delineation of structures and the creation of interpretation plans.

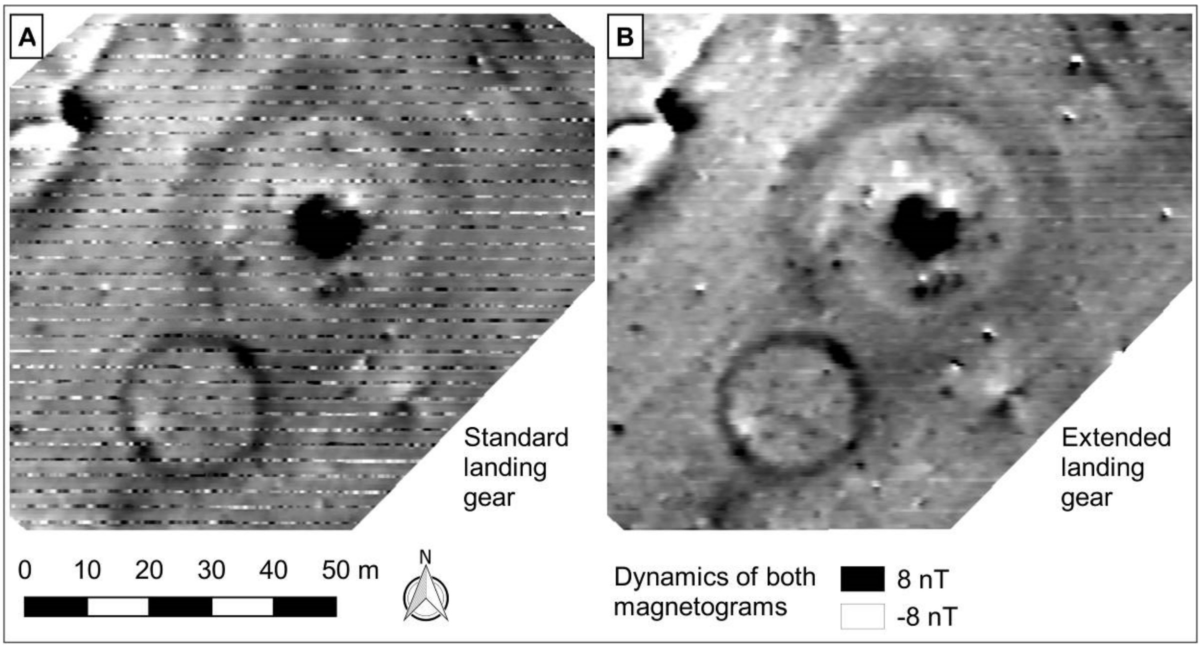

Figure 2: Comparison of the magnetograms produced from Sensys MagDrone R4 magnetometer data. Two flights are shown: in (A) the DJI M350 carried the magnetometer with a standard landing gear and in (B) with an extended landing gear. Instrument height ~0.8 m cm above ground surface, maximum flight speed 3 m/s resulting in a spatial resolution of 0.5 m x 0.02 m (data processing and visualisation: A Stele, data acquisition: C Seisenbacher & G Häußler).

Analysing the frequency components using Power Spectral Densities (PSD) helps to illustrate the effects of the drone on the recordings, as well as the influence of ambient noise signals (Stele et al., 2023). In figure 3, the PSDs of the five R4 sensors are compared for flights using both the standard and extended landing gear. A notable difference is observed, particularly for sensor 3: the standard landing gear causes significantly more disturbance than the extended one. Additionally, the PSDs of sensors 1 and 5 and, to some extent, sensors 2 and 4, show slightly increased noise at lower frequencies with the extended landing gear. This may be attributed to greater vibrations affecting the larger frame and to stronger wind conditions during this flight.

The pronounced 16.7 Hz peak is caused by the nearby railway line, which amplifies interference from the drone. This exacerbates the issues with the third sensor, rendering its data unusable during flights with the standard landing gear (compare with Fig. 2A). Finally, the PSDs reflect differences that are already clearly recognisable in the magnetograms in figure 2 and confirm that the use of an extended landing gear, when combining the MagDrone R4 magnetometer with the DJI M350 carrier platform, results in a significant improvement in data quality.

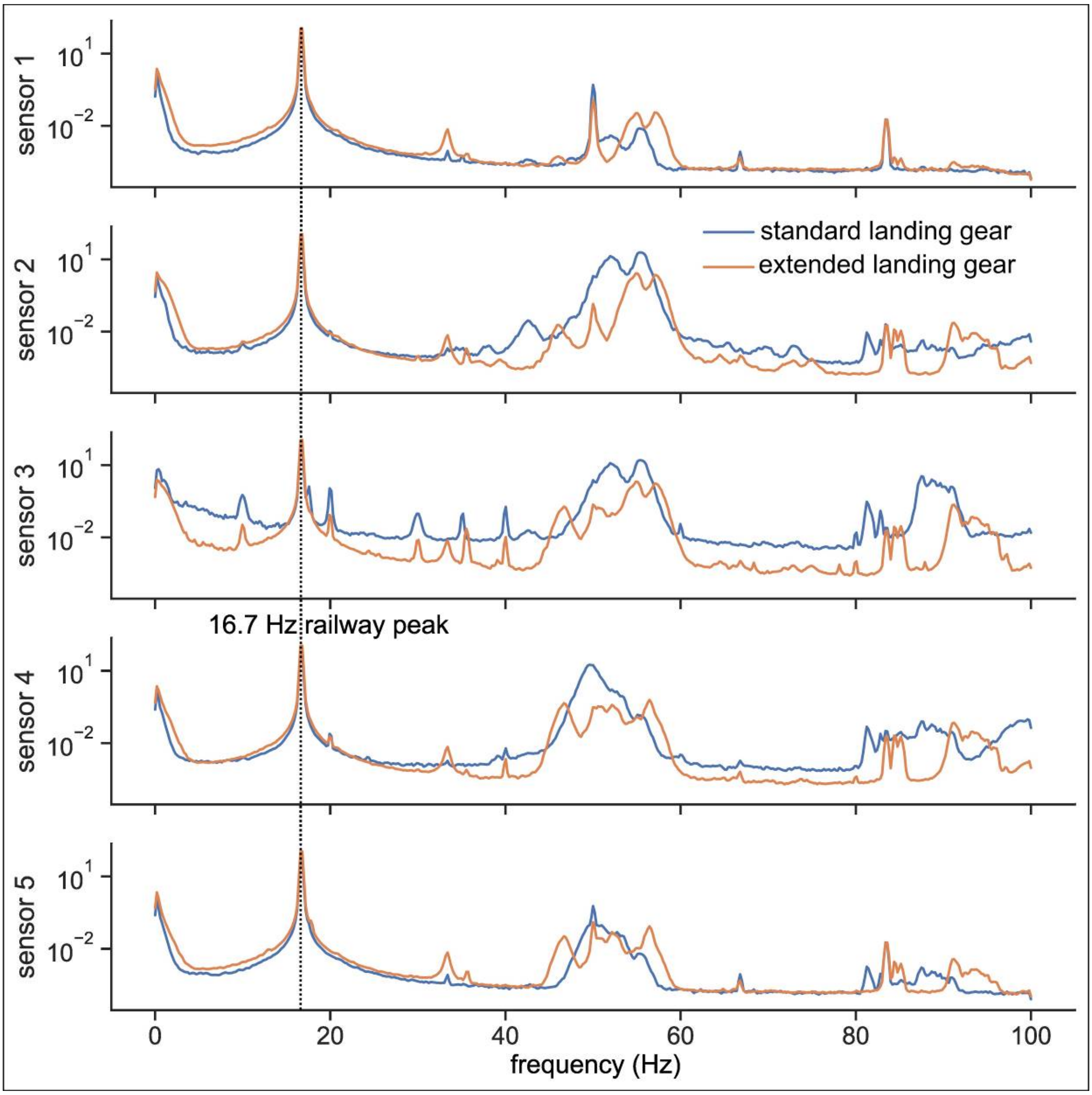

Figure 3: Comparison of the PSDs from drone-based data acquisition with standard versus extended landing gear (data processing and visualisation: L Kaub, data acquisition: C Seisenbacher & G Häußler).

Conclusions

A significant improvement in data quality was achieved with simple adjustments at the landing gear of the drone, notably by increasing the distance between the platform and the sensor frame by just 0.2 m. This improvement is crucial for archaeological prospection, as the ability to use all R4 sensors in drone-based measurements at a flight speed of less than three meters per second enables spatial resolutions of 0.5 m in profile direction and an average of about 0.02 m in measurement/flight direction. This means, the delineation and characterization levels of magnetic survey resolution can be achieved, in line with the standards set by Schmidt et al. (2015).

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VALIDATING BROADBAND MULTISPECTRAL VEGETATION INDICES TO REMOTELY DETECT SHALLOW SUBSURFACE ANOMALIES IN TEMPERATE, VEGETATED TERRAIN

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Few subsurface detection studies have used geophysical methods to validate the application and behaviour of broadband vegetation indices (VIs) in high-resolution multispectral satellite imagery, and even fewer have done so in a temperate environment. In this study, we use 37 broadband VIs on eight Maxar high-resolution multispectral satellite images to remotely detect stressed meadow grass and anomalous soil characteristics over an Iron Age fogou (stone-walled underground passage) in Carn Euny, Cornwall, UK. The highest performing VIs are identified and validated using a two-tier approach. Initially, we correlate the VIs with gravity and then, for a best performing image subset, we perform structural similarity index measurements (SSIMs) and 2D cross-correlations with ground penetrating radar (GPR) data. By doing so, we find the VIs most sensitive to variations in vegetation stress from meadow grass overlying the fogou. In summer months, when ambient temperatures are high, the Iron Oxide index, Soil Salinity Index 7 (SI7) and the Structure Insensitive Pigment Index (SIPI) are most responsive. By analysing their spectral profiles, gradient magnitudes, false colour composites (FCCs) and edge effects, the fogou’s effect on soil salinity, iron oxide concentration and chlorophyll production are understood. From this, we propose a workflow for subsurface detection, in which the SI7 and SIPI vegetation indices are optimised for subsurface detection using gradient magnitude, pansharpening and clipping routines. We review this image processing workflow on two experimental sites in Normandy, France, where in summer months, the location of an underground drainage pipe and two buried ditches are identified, aligning with GPR observations.

A Pilgrim’s Journey: Gradiometer and LiDAR Surveys of two Islands of ecclesiastical significance on Lower Lough Erne, Enniskillen, County Fermanagh, Northern Ireland

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The shores of Upper and Lower Lough Erne and the immediate hinterland are rich with remains of built heritage, including castles, churches and country estates. The nature of this built heritage has been shaped by the lacustrine landscape, with the Erne Waterway acting as a boundary, as well as a route way since the prehistoric period. Amongst these remains are over 30 sites of spiritual or ecclesiastical significance including as many as 12 church sites recorded near the Lough. In Early Christian periods (400 – 1000 AD), the Erne Waterway was used as a routeway between these island monasteries. This was continued into the Middle Ages when the waterway formed part of an important pilgrim route to St Patricks Purgatory in Donegal.
The Lough Erne Pilgrim Way project seeks to create a journey to celebrate the ecclesiastical history of the area by developing key sites around Upper and Lower Lough Erne. To this end, Wessex Archaeology was commissioned to undertake a combined gradiometer and LiDAR survey of two islands located on the Lower Lough Erne waterway; White Island North and Davys Island. The project is being led by Fermanagh and Omagh District Council, in partnership with Waterways Ireland, Department of Communities for Historic Environment Division and through funding from the National Lottery Heritage Fund.

Figure 1: Site location (Wessex Archaeology)

History of the Islands

White Island North is most famous for its unique ecclesiastical site on which the ruins of a medieval church (SMR: FER 173:002) is located on the eastern shore. The church, thought to be built in the 12th century and ruined by the 17th century is most noted for containing seven enigmatic stone figures. These figures are thought to pre-date the church and although its unknown whom they depict they are thought to represent early medieval pilgrims (Megalithic Ireland 2023). County Fermanagh has a rich tradition of stone carving from the prehistoric to medieval period with many of these figurines being found within the region. The discovery of a head and unfinished figure (Lowry-Corry, 1959) found during renovations of the church on White Island North tantalise the possibility that these sites were not only centres of pilgrimage but manufacturing sites producing religious icons.

Davy's Island is situated to the south of White Island North and recorded on the eastern side of the island is a 12th century church and enclosure (SMR: FER 173:0100. The church is a simple Romanesque building, possibly connected to Kiltierney Abbey, of which only the remains of the south-east wall and the foundations of the north-east gable remain intact. A circular graveyard surrounds the church, which itself is enclosed by a series of earthworks which are now barely visible due to tree growth.

Figure 2: White Island North Figurines (Patricia Edwards)

Little is known about these islands beyond their ecclesiastical history and it was hoped the results of the survey might identify new information about how the pilgrims thrived in the waterways of Lough Erne.

Survey approach

Each island had its own unique set of site conditions and archaeology to record. A multidisciplinary approach was employed to detect previously unrecorded archaeological remains for each island. Above and below ground was surveyed with non-intrusive techniques of detailed gradiometer survey and unmanned aerial vehicle (UAV) mounted LiDAR survey. Whilst it was possible to carry out both survey techniques on White Island North, dense tree cover meant that only LiDAR survey was possible on Davy's Island. Access to both sites was via boat, which limited what equipment could be used. The gradiometer survey was conducted with a Bartington Grad-601 and the LiDAR survey was undertaken using a DJI Matrice 300 (M300) UAV equipped with a Yellowscan Mapper LiDAR sensor.

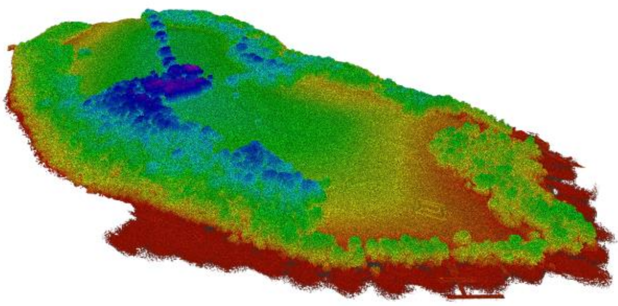

Figure 3: White Island North point cloud colourised by elevation (Anthony Russell)

Results of the surveys

The LiDAR and gradiometer surveys were successful in detecting new archaeology on both White Island North and Davys Island. The features found range from possible prehistoric and agricultural activity to Early Christian settlement activity, medieval ecclesiastical and agricultural activity, and modern landscaping. Collection of complimentary datasets for White Island North allowed for data comparisons that demonstrated several archaeological features would have been misinterpreted without this multidisciplinary approach. The results of these surveys are comparable to findings on other islands within the Lough Erne waterways, however they are recorded in much greater resolution and tell the story of the long and varied history of Lough Erne and these islands.

Scan this link to access an interactive story map of the project.

Figure 4: QR code to story map (Wessex Archaeology)

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New geophysical surveys along the course of the Dorchester Roman Aqueduct

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This paper will present the results of the first systematic survey along the Dorchester Roman Aqueduct, the course of which follows a *c.* 20km route along the Frome valley in South Dorset, UK. Despite over 100 years of investigation, only a limited amount is known about the aqueducts true course, construction history, and source of water. This is because only very short lengths of the aqueduct can be seen as earthworks as much of the structure has been obfuscated through subsequent agricultural practices and urban development. Recent archaeological investigations have, however, identified the location of the aqueduct in a hitherto unknown location (Manley *et al.* 2024). This has confirmed a previously postulated route (Farrar 1970) and ruled out other sources of water (eg Coates 1902; Putnam 1998), but has also opened up further questions regarding the aqueduct's precise course and phasing. In particular, it has been suggested that along parts of the Dorchester Aqueduct were constructed in at least three phases (Sparey-Green 1987; Putnam 2007), but this is difficult to attest to from the ground surface. Consequently, targeted geophysical survey of uncertain elements of the aqueduct's course has been undertaken to elucidate its construction history.

Although the conjectured presence of aqueducts in Roman towns and cities is well documented, specific evidence for locating them beyond the extent of settlements is surprisingly limited, especially considering the applicability of using geophysical techniques for this task. For example, gradiometer survey has been used successfully in the vicinity of the Winchester Aqueduct and identified sections of its possible route (Fasham et al. 1991; Richardson 2018), but beyond identifying the location, little attention has been paid to ascertaining the character and composition of these structures. Despite this, the evidence from Dorchester suggests that the aqueduct was quite dynamic having, been 'cut' and clay-lined, abandoned, , and then 'recut'. This research, funded by the NSGG and ISAP, attempts to improve on this understanding of using a combination of geophysical survey techniques.

At strategic locations within the Frome valley, gradiometer surveys were used to locate the course of the Dorchester aqueduct in the first instance. This was followed by more focused use of Ground Penetrating Radar (GPR) to characterise specific components of the aqueduct channel(s). In addition, Electromagnetic surveys were carried out using a CMD Mini Explorer to provide complementary information and assess the instruments' ability and applicability on this type of buried archaeological monument. Although the results are currently at a preliminary stage, the results have provided significant details regarding the nature of the aqueduct and enhanced the understanding of its evolution.

There has been a lack of targeted investigation of Roman aqueducts in Britain primarily because they can be very challenging to locate, being deliberately located underground, with limited surface expression (cropmarks or earthworks). Although they typically follow contours, given that aqueduct features are similar in form to ditches, interpreting these structures can be problematic (Stewart *et al.* 2020). The results of this research, however, further demonstrate the applicability of the different geophysical methods to enable more informed interpretations, which could be applied in any future investigation of these monuments elsewhere.

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REVIVAL OF GEOPHYSICAL MEASUREMENTS IN ASHUR (IRAQ)

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Introduction

Ashur (modern Qalʿat Sharqāṭ) was the Assyrian Empire Ashur's first capital and Assyria's ancient religious capital. The name Ashur was applied to the city, to the country, and to the principal god of the ancient Assyrians (Britannica, 2015). The city is situated on the west bank of the Tigris River at a slight elevation ca. 10 m above the average water level above the Tigris. The inner area covers ca.1.5 square km – 2000 m in the north-south direction and ca. 500-700 m in the east-west direction. The terrain with the old excavation trenches and giant heaps of ground forms a rather bumpy and uneven area, so wheeled-devised multi-channel magnetometry is utterly impossible. The same applies to geophysical drone prospecting. The site was already occupied from 2500 BC until 614 BC when the Babylonians destroyed it. A part of the city was later revived during the Parthian period in the middle of the 2nd century BC. The first scientific excavations there were conducted by Walter Andrae (1903–13). From 2014 until 2018, the site and excavation house of Ashur served as a headquarters for ISIS. Walter Andrae investigated this large area from 1903 on by digging a total of 10 excavation trenches 5 m wide and up to 700 m long in the east-west direction parallel to each other in the north-south direction. These trenches and heaps of the excavated ground impede a complete magnetogram and force us to produce a mosaic of magnetograms across the entire city, even by applying the handheld magnetometer.

Fig. 1: Map of Mesopotamia and Iraq.

Archaeological Geophysics

Barthel Hrouda, head of the Institute of Near Eastern Archaeology at Munich University, pioneered geophysical methods in the Near East by inviting us for magnetometer prospection in 1989. Only 34 years later, we got the chance to complete our measurements during the spring seasons of 2023 and 2024.
Our first magnetometer survey, conducted in April 1989 with a caesium magnetometer, covered roughly 2 ha. Therefore, the new geophysical survey in Ashur aimed to obtain an overall overview of the organization and design of the entire city and provide a solid basis for initial excavations in the lower town of Ashur.

Results

The intensity of magnetic anomalies in Assur are in a similar range and compared to those of other archaeological sites in Iraq, e.g. Peshdar Plain and Khorsabad in the north and Uruk, Fara, or Isin in the south. Earth’s magnetic field in Ashur 2023/2024 ranges around 46,177.5 ±17 Nanotesla; magnetogram images – similar to other Iraqi sites – are dominated by relatively strong magnetic anomalies in the ± 30-40 Nanotesla range. This finding is interesting because it means that the intensity of anomalies reflects intensive settlement and land use rather than the very different geological conditions in the different parts of the country. The alluvial sediment of the Tigris River dominates the examples from the north of Iraq, while in the case of Fara, Isin, Uruk and Ur, Euphrates sediments have different magnetic properties.

The first impression of the magnetogram of the entire area, processed as total field measurement without filter, reveals a large variety of magnetic enrichment of the topsoil. Dark areas of magnetic-enhanced topsoil indicate high activity due to the use of fire and, as a result, the contamination with magnetic minerals. We found areas with lighter colours in the southwestern part of the lower town but partly between some city quarters and in the northwestern part of our survey area.

When interpreting the results, we must limit ourselves to analyzing building complexes' ground maps and orientation. One can identify kilns by their high magnetic intensity and remanent magnetization. Further details, e.g. about the size and the function of the buildings, we will present in a final publication. It turned out that the uneven topography also plays a significant role in the shape of anomalies and is reflected disproportionately in the results. Excavation trenches and slight depressions of the ground show up as negative anomalies. At the same time, small mounds of excavated Earth already generate high magnetic anomalies and can easily lead to misinterpretation if the topography is not considered. One must, therefore, be clear: Apart from a few exceptions, precise consideration of the topography is necessary for these anomalies to be assessed and interpreted. Caution is also advised when interpreting fireplaces. Ideally, this feature can only be distinguished by the metal scrap in modern barbecue fires but never inside ancient kilns. Furthermore, magnetic anomalies from sundried mudbrick walls can be positive and negative; in the worst case, they fade out without contrast to the adjacent soil. The interpretation of the magnetogram in the “Neustadt” highlights the presence of circa 180 buildings, more than 100 pyrotechnological installations (kilns), and the clear magnetic traces of a lightning strike in the centre of our survey area. We identified circa 41 000 m² built-up area of the 150 000 m² measured area.

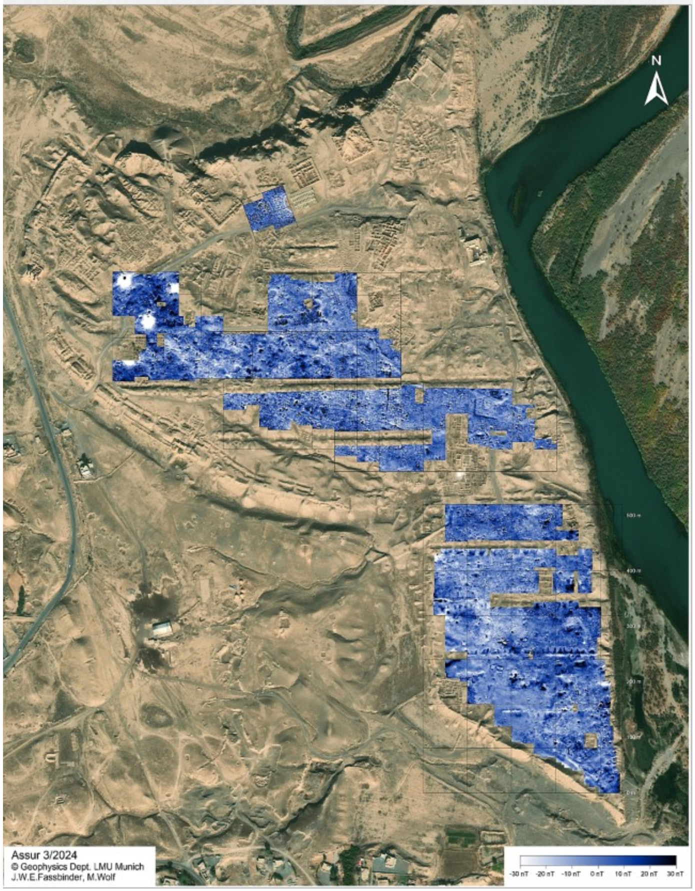

Fig. 2: Ashur. Magnetometer measurement of the survey areas.

Conclusion

The range of magnetic anomalies for Iraq on more than 20 different archaeological sites we surveyed so far in the modern state of Iraq is relatively high (±30-40 Nanotesla). Unlike the measurements in the Peshdar Plain in Iraq-Kurdistan or Uruk in the south of Iraq, the results of our measurements are somewhat blurred and sometimes complicated to interpret. What makes it even more difficult is that modern iron-containing waste and the remains of barbecue sites from local tourists heavily contaminate the area. Therefore, the final interpretation of the magnetograms benefits from the application of further geophysical methods such as soil and mineral magnetic analysis and resistivity survey. However, further input from archaeologists and their knowledge of comparative excavations, layouts and ground maps of houses play a fundamental role in the comprehensive interpretation of the data.

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INTERACTIVE, SHALLOW MACHINE LEARNING-BASED SEMANTIC SEGMENTATION OF GEOPHYSICAL DATA FROM ARCHAEOLOGICAL SITES

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Introduction

In the last decades, technological developments such as the use of vehicle-towed sensor arrays and centimetre-precise positioning have led to growing data volumes, which can be processed and visualised efficiently. An important bottleneck is now at the stage of data interpretation. Manual delineation and classification of the significant anomalies are time-consuming, and different methods for (semi-) automatic segmentation have been proposed (e.g. Schmidt and Tsetskhladze 2013; Linford and Linford 2017). These can broadly be divided in ‘hand-engineered’ algorithms, where the user formulates the rules, and machine-learning based techniques. In the latter category, deep convolutional neural networks (DCNNs) achieve high accuracy and speed, but they rely on large, manually labelled training sets, not yet available for archaeological geophysics (Küçükdemirci and Sarris 2020). So far, (semi-)automated methods have not been used widely in archaeological geophysics, because of the complexity of the segmentation task (low contrast between the archaeological structures and the background), and the low predictability of the targets.

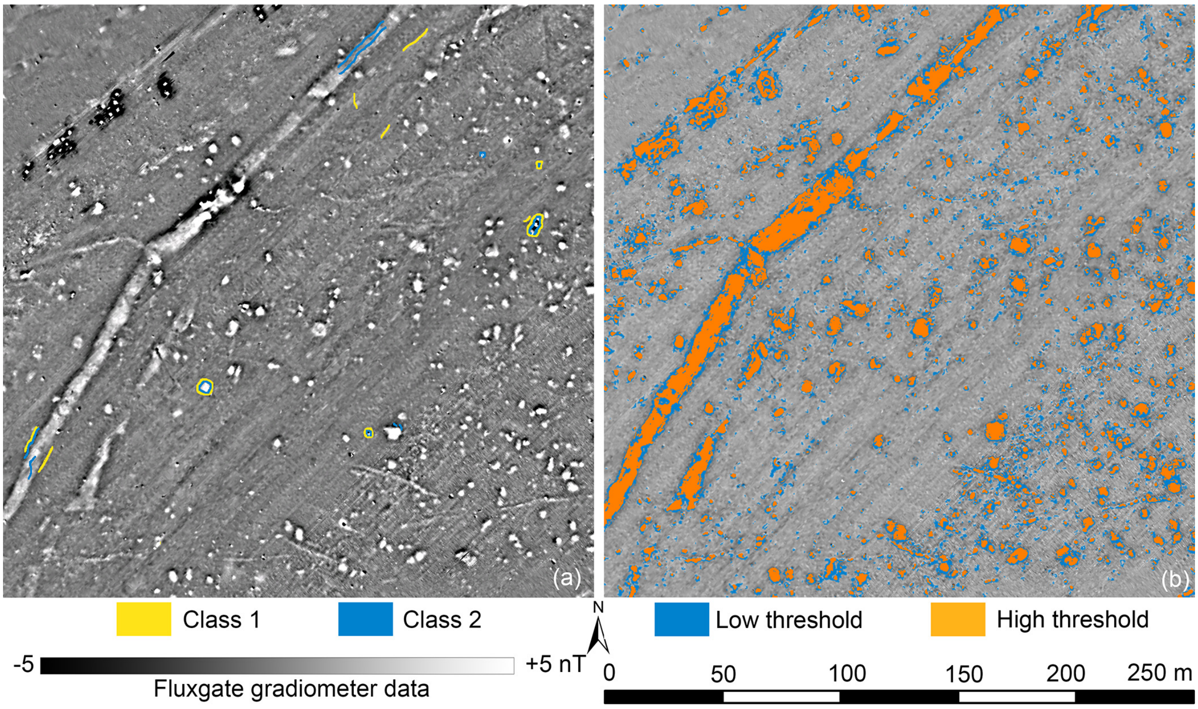

Figure 1: Pixel segmentation in ilastik. (a) Magnetometer data from the Iron Age site Boviolles, France, with annotations representing background (Class 1) and archaeological structures (Class 2). (b) The two thresholds used for hysteresis thresholding (low = 50 %, high = 75 % probability).

Powerful open source tools for medical image segmentation, based on shallow machine learning, have been developed, which can partially overcome these limitations (e.g. ilastik: Berg et al. 2019). They require only few user annotations, so that they often represent an optimal compromise between speed and accuracy. They can also be used to interpret near-surface geophysical data.

Interactive image segmentation based on shallow machine learning

Machine learning algorithms calculate properties or 'features' of the input data. Whereas DCNNs create these features automatically, in shallow machine learning the classifier learns from a set of predefined features, for example the gradient magnitude. The user draws brush strokes on pixels representing at least two classes (archaeological objects and background) (Figure 1a). The classifier is trained almost in real time and the classification can be improved by adding more labels, in an iterative way. The default classifier is the Random Forest (RF; Geurts et al. 2014). The probability maps predicted by the RF are converted into a segmentation by applying hysteresis thresholding (Canny 1986) to the 'archaeological structures' class (Figure. 1b). Hysteresis thresholding selects pixels with probability values above a low threshold if they are connected to at least one pixel with a probability above a high threshold.

Objects are created by merging segmented pixels. To classify them, object features are calculated (e.g. the size or convexity). This is similar to rule-based object classification approaches, although it is entirely machine learning based: the operator selects the features, but the classification is generated by a RF.

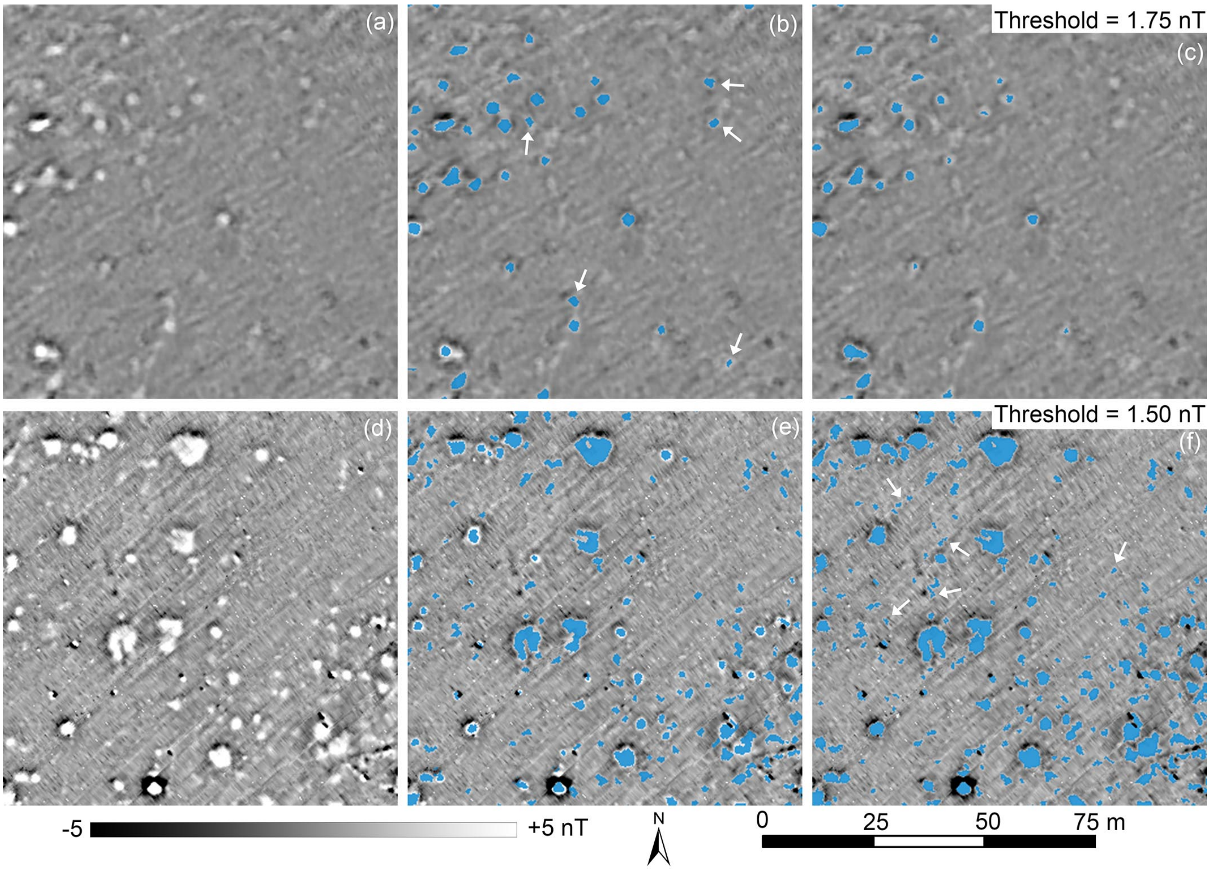

Figure 2: (a, d) Magnetometer data from Boviolles, used to compare our method (b, e) with the application of a simple threshold, at 1.75 nT (c) and at 1.5 nT (f). The arrows in (b) indicate the undetected pit structures in (c). The arrows in (f) denote noisy areas not included in (e).

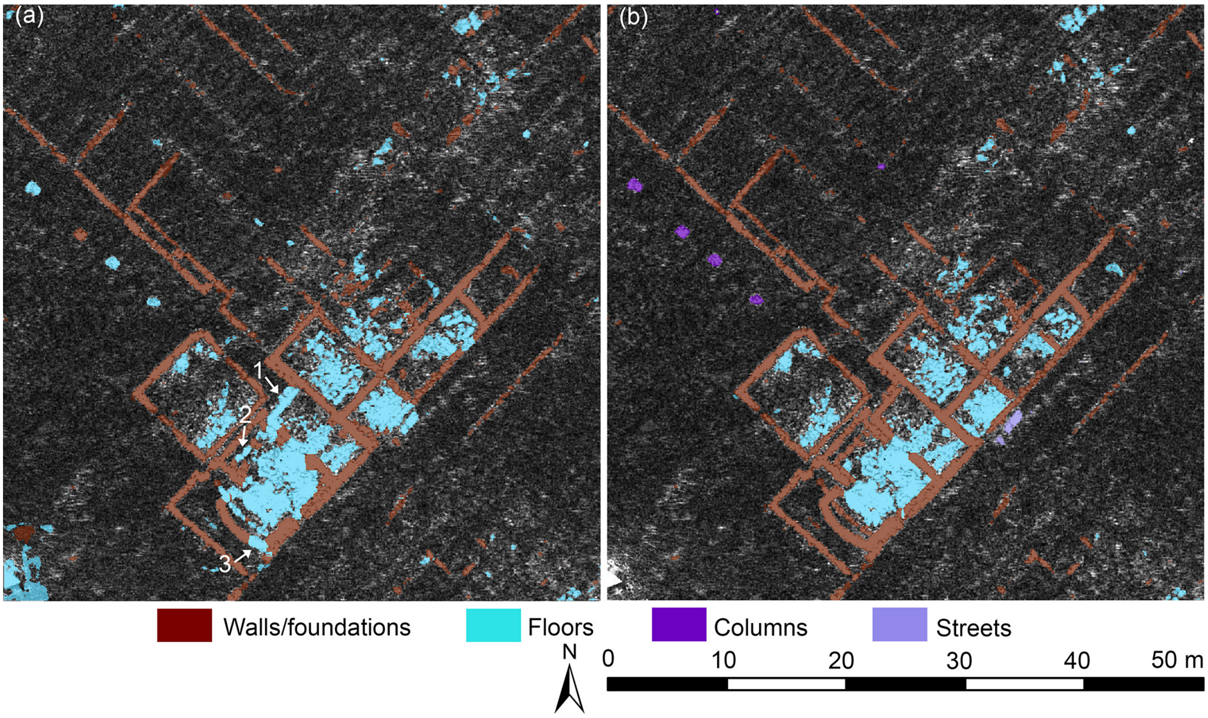

Figure 3: GPR data from Interamna Lirenas, Italy (slice at an estimated depth of 0.65–0.66 m). (a) Object classification with examples of objects wrongly classified by the RF (arrows 1–3). (b) After manual reclassification.

Segmentation errors can be curated manually: entire objects can be reclassified, or the correction can occur at pixel level. The final step is to convert the objects to vector polygons suitable for visualisation and analysis in a GIS. These tools can handle 3D geophysical datasets as volumes, instead of treating them as separate 2D images.

Results and discussion

After RF pixel classification, the 'archaeological structures' class includes all but the very subtle traces. Comparison with a simple threshold (Figure 2) demonstrates the ability of the RF to select the relevant structures while eliminating the noise. For the more detailed classification of the 'archaeological structures' class, we let the RF object classifier distinguish between few classes only, whereas the objects belonging to minority classes are classified manually, because making the RF distinguish between many classes results in a large number of wrong classifications.
To assess its accuracy when applied to GPR data from a Roman town (Interamna Lirenas, Italy), we compared the RF object classification (Figure 3a) with a manual interpretation by an expert (A. Launaro; Launaro and Verdonck 2023). The mean Intersection over Union (IoU) of the 'background', 'wall' and 'floor' classes was 56.6 %. Manual correction (Figure 3b) slightly raised the mean IoU (60.8 %). Remarkably, these scores are not much lower than the comparison between two independent, fully manual interpretations (by A. Launaro and by L. Verdonck), which resulted in a mean IoU of 61.8 %. Besides obvious segmentation errors by the RF (e.g. undetected structures weakly contrasting with the background), other differences between RF and human interpretation cannot be considered erroneous, but illustrate the uncertainty inherent to geophysical data interpretation (e.g. shallow furrows causing slight variations in the physical contact between the GPR antennae and the

soil are hardly distinguishable from linear archaeological structures with similar orientation). Therefore metrics such as IoU cannot serve as objective evaluation measures.

Manual user intervention can optically improve algorithm results (even if quantitative improvements are small), but is time consuming (manual pixel annotations in particular). However, this should be contrasted with the time needed to run a fully manual analysis. Our experiments with shallow machine learning halved the time required for entirely manual interpretation; the 3D GPR dataset was analysed approximately three times faster.

Acknowledgements
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie grant agreement No 945298 and from the Paris Region, under the 'Paris Region fellowship Programme'.

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GPR SURVEY PROVIDES EVIDENCE FOR A BRICKED CELLAR UNDERNEATH A BAROQUE GARDEN PAVILION AT MEMMINGEN (BAVARIA)

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Site description and project target

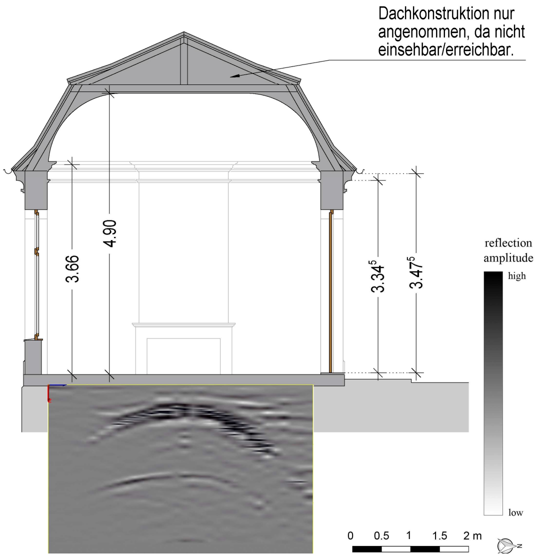
The so-called 'Hermansbau' is located in the north-western historic centre of Memmingen (Allgäu, south-western Bavaria). The 'Hermansbau' was built in 1766 for Benedikt Freiherr von Herman together with a Baroque garden and depicts the most important testimonial of the Memminger aristocratic upper class (Breuer, 1959). The pavilion within the former Baroque garden also dates to ca. 1766. It is a one-storey building with a mansard roof (Figure 1a). The interior is decorated with mural paintings showing landscapes, and many stucco decoration of rocailles and putti (Figure 1b) (Breuer, 1959). Due to its bad state of preservation, a restauration campaign started in 2022. Already in the beginning, hints for a bricked vaulted cellar underneath the pavilion have been found during the opening of a small trench on the floor. Nothing is known about this construction, as the position of the former entrance is unsure and only some ventilation openings in the pavilion's foundations gave a hint on a potential vault. Therefore, in winter 2023, we tried to gain more information on the size and layout of this construction by executing a GPR survey with a 900 MHz-antenna inside the pavilion. The survey covered the complete accessible area of 4.2 x 6 m. Despite disturbances by a metal plate in front of the fireplace at the western wall and the air-filled space underneath the wooden floor, the results are quite promising.

Figure 1: Garden pavilion of the 'Hermansbau' in Memmingen. (a) Photo of the exterior from the north. (b) Photo of the interior decoration (Photos: M. Forstner, BLfD).

Results

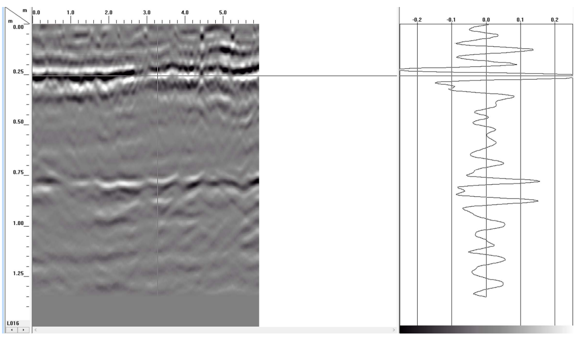
The GPR results show a very distinct elongated reflection anomaly in the centre of the grid in only 15 cm depth that subducts to both sides, i.e. towards the northern and southern wall of the pavilion, until up to 80 cm below the surface (Figure 2). The reflection anomaly extends over the whole length of the grid in east-west direction. Therefore, it can be assumed that it depicts a barrel vault (Figure 4).

Figure 2: Cross-section at 2.2 m profile distance to visualize the layout of the vault. Overlay with a lateral cut through the pavilion (GPR data: Roland Linck, BLfD; Pavilion's section: Zettler Bau Memmingen). For migration, an average velocity of 0.2 m/ns was used. GSSI SIR-4000 with 900 MHz-antenna, sample interval 3 x 10 cm. Project-No. Pav23rad.



It should be noted that the anomaly seems to vanish towards north and south. On the one hand, the reason could be due to Snell's law of reflection: Starting at a specific inclination of the vault, the GPR signal is reflected away from the receiver and cannot be detected anymore. On the other hand, as the anomaly can be traced up to a deeper level at the northern part than at the southern one, the above-mentioned, small trench could also cause this effect. However, it can be assumed that in reality the vault is using the foundations of the pavilion and extends to the full width. Due to the dense profile spacing of 10 cm, it is possible to create sections in cross-profile direction to visualize the internal layout of the cellar (Figure 2). Which again proofs that the detected structure shows a vault due to the hyperbolic shape of the anomaly. Furthermore, the analysis of the corresponding wiggle traceplot reveals that the cellar is an air-filled cavity due to the negative, reversed first peak of the signal (Figure 3). Qawesmeh et al. (2021) published a comparable signal behaviour for a similar feature. Approximately 60 cm below the ceiling of the cellar, another parallel reflection anomaly can be identified (Figure 3). Possibly, this structure can be interpreted as the cellar's floor, as the signal polarity is changing again and a transition from air to soil seems obvious. The reason of the apparently quite small height of the cellar is probably that the electromagnetic signal velocity of 0.1 m/ns is underestimated during data processing and the distances within the air are compressed (see Qawesmeh et al. (2021) and Linck & Zickgraf (2024)). Executing the Kirchhoff-migration with an average velocity of 0.2 m/ns calculated by the soil velocity (0.1 m/ns) and the one of light (0.3 m/ns), reveals a more realistic height for the vault of 1.1 m. Therefore, all depth information in this case study have to be treated with care, as the electromagnetic velocity is varying strongly between soil and air-filled cavity. The faint uparching of the supposed floor could also be due to the variations in the signal transmission velocity compared to the surrounding undisturbed soil. However, another interpretation

Figure 3: Profile view including wiggle traceplot (on the right) to illustrate the reversed first peak indicating an air-filled cavity.



approach of this feature as a multiple reflection of the ceiling is possible. In this case, the real floor level of the cellar could not be reached by the high-frequency antenna and the resulting shallow penetration depth. As another survey with a 400 MHz-antenna shows no other structure, the interpretation as floor seems indeed more likely. In Figure 4, the layout of the Baroque cellar was modelled in 3D by Voxler to visualize the location underneath the pavilion.

Figure 4: Photogrammetric 3D-model of the Baroque garden pavilion with the modelled GPR results of the barrel vault displayed underneath. The blue lines illustrate the position of the bricked vault.

As a conclusion, it can be stated that the GPR data now give evidence for the layout and structure of the supposed bricked barrel vault underneath the Baroque pavilion of the ‘Hermansbau’ in Memmingen for the first time. Similar results could not have been gathered without opening the whole floor of the building.

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GETTING UNDER THE SKIN OF THE SERPENT'S TAIL: IMAGING THE BURIED STONES AND STONE HOLES/PITS OF THE BECKHAMPTON AVENUE, AVEBURY

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Background

Running 1.5km westward from Avebury, the Beckhampton Avenue links the Avebury henge to the Longstones Cove, the avenue being the essential tail component of Stukeley's serpentine temple, the *Abury Dracontia* (Stukeley 1743). Comprising of pairs of evenly spaced standing stones, only two are now extant at the very end of the Avenue. Indeed, episodes of large-scale stone destruction that took place after Stukeley's fieldwork led to subsequent doubts about its very existence until this was finally confirmed by excavation in 1999. Despite this affirmation, we know little of its full course and character.

Recent Work

A programme of multi-method geophysical survey conducted in 2022 succeeded in mapping a newly discovered 120 m stretch of the Avenue encompassing six stone pairs, shedding important light upon its course, form, and the fate of the standing stones that once marked its course (fig. 1).

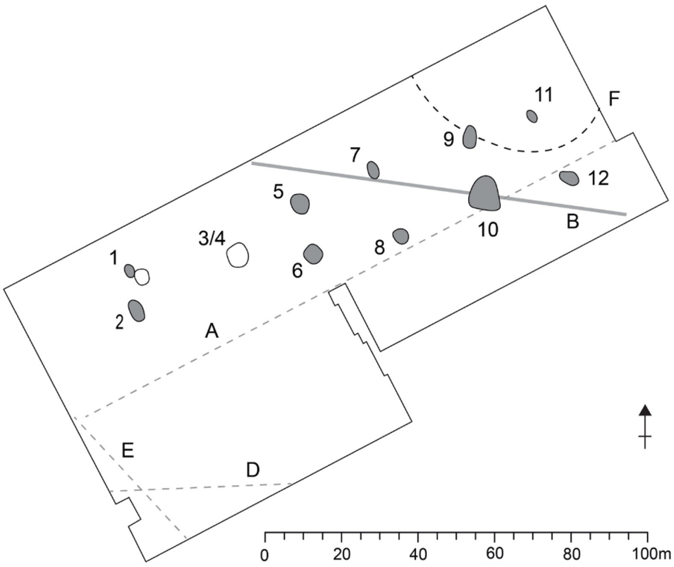

Figure 1: Layout and numbering of the newly discovered Beckhampton Avenue stone pairs.

The existence of the Avenue at this location was suggested by a more limited earth resistance survey undertaken in 2005 (Gunter & Roberts 2005), and so this work aimed to confirm and expand on these initial promising results. It also aimed to further assess the effectiveness of a wider range geophysical techniques for characterising such remains. The techniques employed were magnetometry (fluxgate gradiometry), earth resistance, earth resistivity imaging (ERI), frequency domain electromagnetic induction (EMI) and ground penetrating radar (GPR).

This Paper

A general account discussing the overall results and the broader context of the 2022 surveys has been published in Gillings et al. (2024), and so this paper looks in more detail at the geophysical survey results, including further processing, 3D imaging of the buried stones (figs 2 & 3), and importantly the EMI results that were not discussed in detail in that paper. It also seeks to offer a coherent methodological blueprint for future geophysical surveys that seek to recover evidence of Avebury's former megalithic fabric.

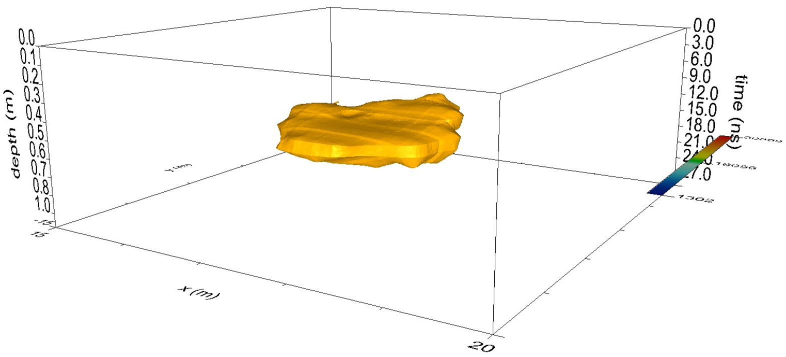

Figure 2: GPR Slice™ isosurface of buried megalith 12

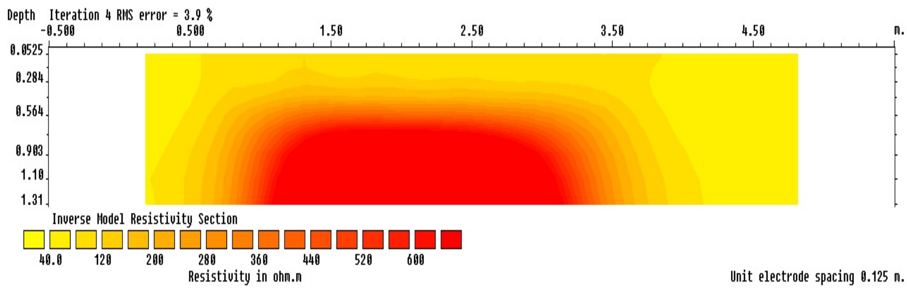

Figure 3: Res2DInv inversion of the ERI data for buried megalith 7

Acknowledgements

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Heading West from Vester Vandet? Interpreting the traces of a Viking-age and high-medieval site in North-Western Denmark.

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The site of Vester Vandet is located by the inland lake of Vester Vandet, close to both the rough coast of Vesterhavet and the inland fjord of Limfjorden in North-Western Denmark (see Figure 1). The site is known for its numerous metal-detecting finds from the Viking- and early medieval times, including coins, jewellery, brooches, fittings, locks, keys, and lance points. Investigations undertaken between 2011 and 2014 revealed well-preserved archaeological layers and features, including pit houses, thick cultural layers and houses dating to the 12th and 13th centuries. All of this indicates some form of complex settlement with far-reaching contacts, as well as indications of fishing activities and possible textile production (Andersen et al., 2015). The question is how to interpret the site, given its geographical location. Is it a local fishing village, a harbour site as a safe harbour for long-reaching travellers when the ocean of Vesterhavet got too rough, a hub for manufacturing and repairing sails, or an important trading site linking the outer ocean to the entire Limfjord-area to the southwest?

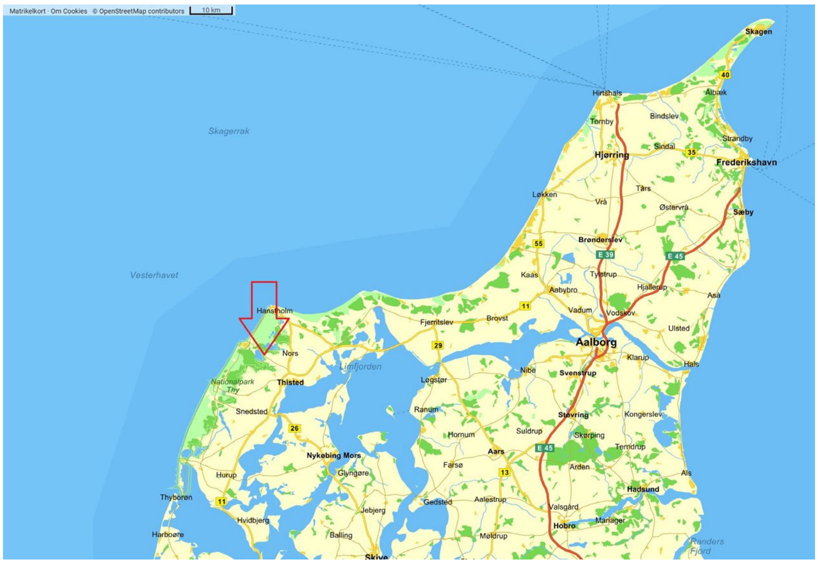

Figure 1: The location of Vester Vandet in North-Western Denmark. Source: Open Street map.

Recent large-scale geophysical investigations initiated through the PastCoast project (Stamnes, 2022) reveal the presence of a very large activity area, with several hundreds of pit houses, several enclosed settlements, past roads and related features – giving new and vital information on how to understand this site. The new evidence points towards the largest coastal activity site known in Northwestern Denmark, making Vester Vandet an important hub linking the outer coast to the larger inland towns and transportation routes. Still, exactly how to interpret the site and its function or functions is still debatable.

Large-scale Ground Penetrating Radar and Magnetometer surveys
Recent geophysical surveys combining large-scale ground penetrating radar (GPR) surveys and magnetometer-surveys indicated a wide range of new observations. The magnetometer-data covers about 6 hectares, and indicate settlement enclosures and maybe as many as 150 pit houses, which can be seen as 3-5m round circular positive anomalies (see figure 2). This interpretation is backed up by direct comparison of archaeological evidence from earlier excavations.

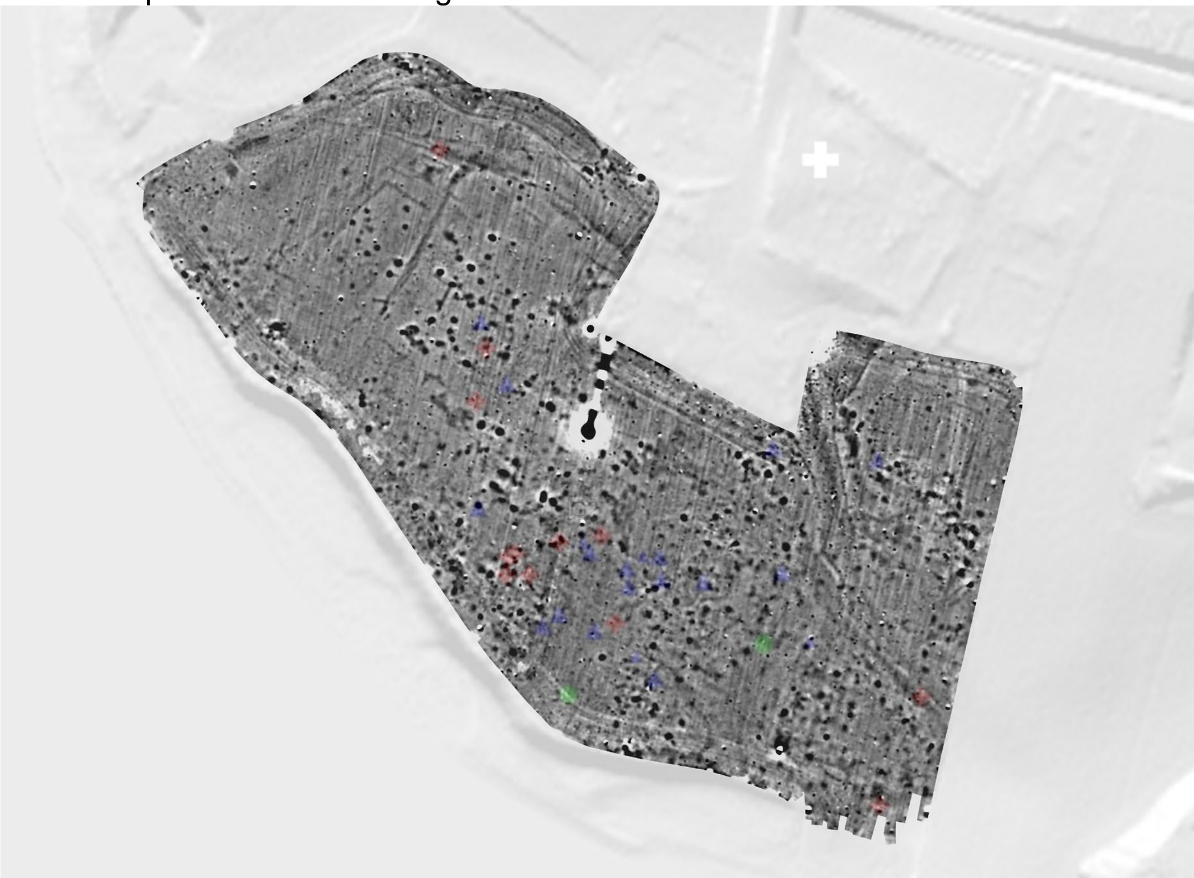

Figure 2: Magnetometer plot from Vester Vandet. Max 5 nT (black), minimum -5nT (white).

Detailed analysis of GPR data covering most of the same area indicates the presence of a large amount of larger pits, which colocates well with observations from the magnetometer dataset. While the entire dataset has not been analyzed yet, the parts show three times as many pit-like anomalies as visible in the magnetometer dataset. If this relationship holds true for the entire area, then we might have as many as 400-500 pit houses in this field alone (see figure 3 and 4).

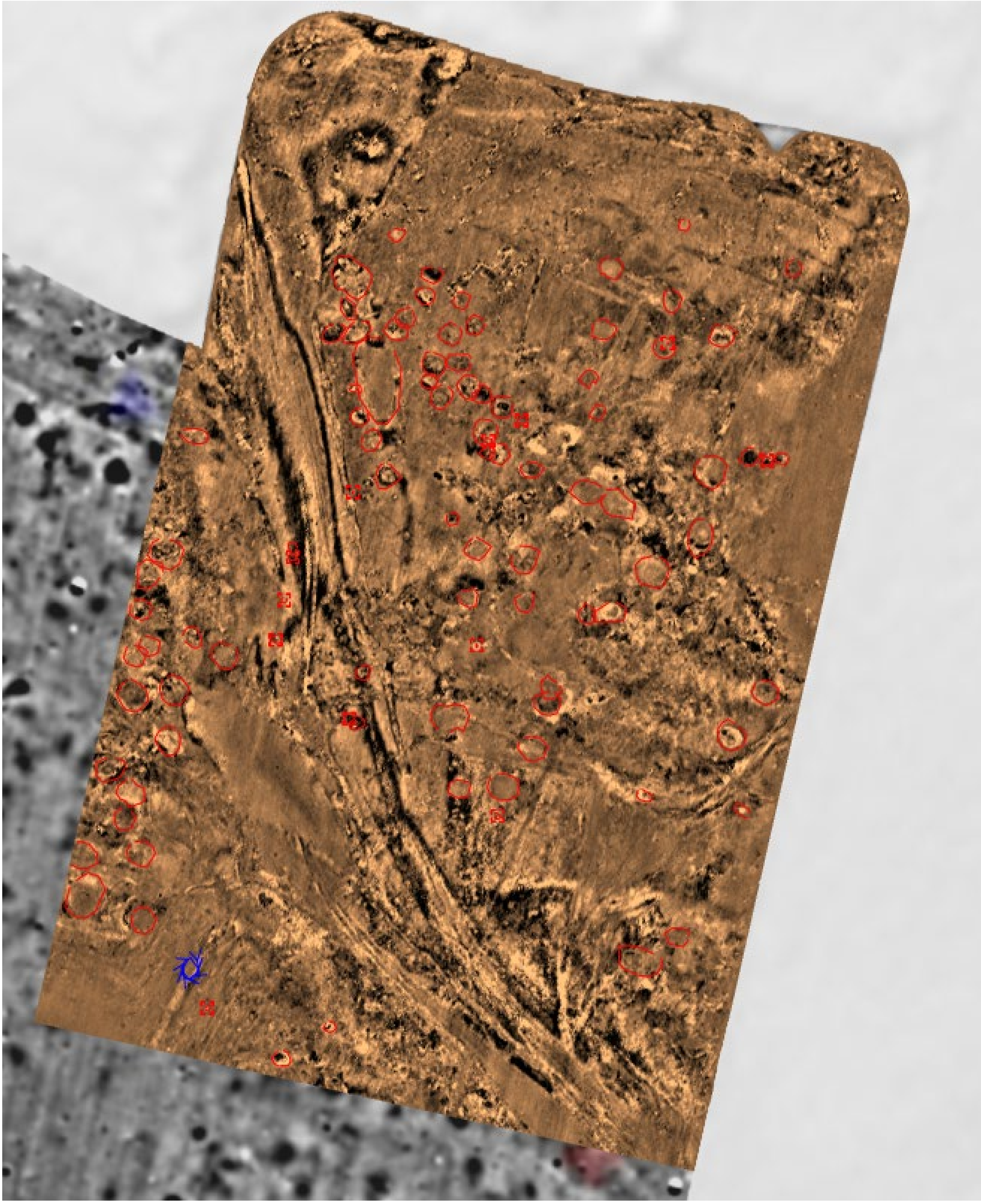

Figure 3: Preliminary interpretation showing the larger pits identified in the GPR data. Depth section from about 90cm depth.

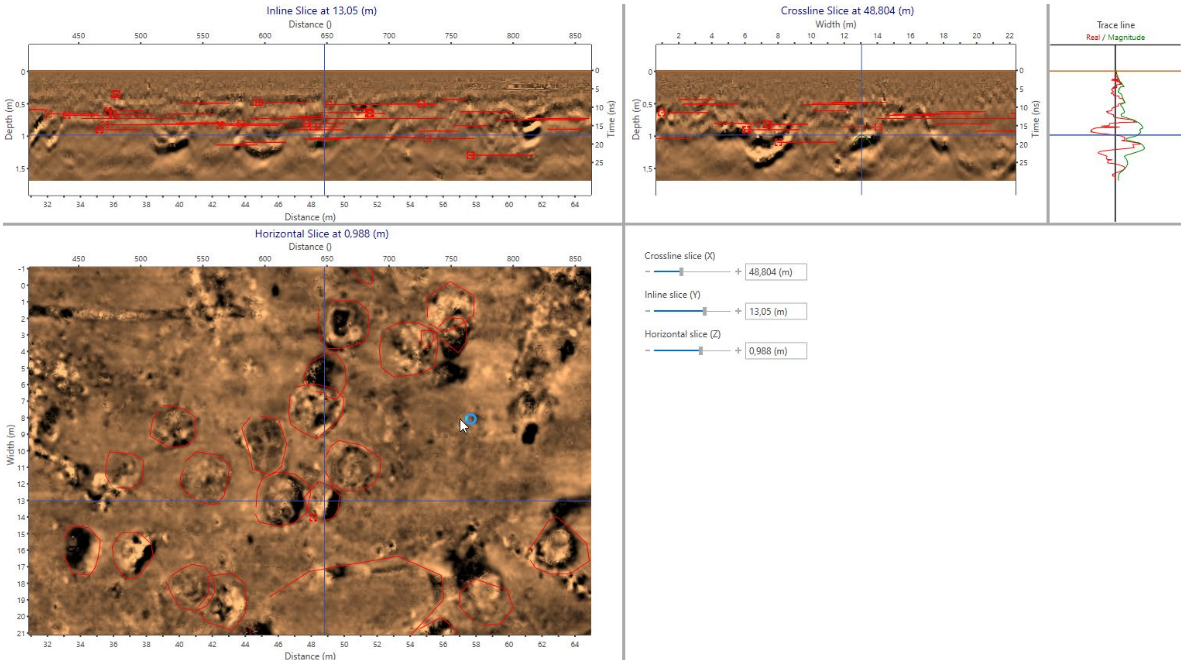

Figure 4: Crossline and inline data example from migrated thick sliced data stitch as presented in the Kontur Examiner software.

Dicussion and conclusion

While the interpretation work is still ongoing, it has become clear that Vester Vandet is one of the Viking-age and high-medieval sites in Northern Jutland that has the highest amount of pit-houses. Its location is just on the edge between cultivatable land to the east and an area of constantly changing drift-sand to the east. This makes the geographical location perfect as a safe harbour while still retaining close contact with the inland agricultural areas and the western shores towards Vesterhavet. Previous investigations from other sites with pit houses show that they are often associated with textile production, including sails and metalworking. At Vester Vandet, there are few observations of slags and oven remains amongst the metal detector finds. We must also assume that not all these pit houses were used simultaneously. It is likely, then, that the site could have served several functions and even may have been a place where larger bands of travelling vessels retracted to while regrouping and waiting for favourable winds to sail towards the British Isles.

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Posters (09:30-17:30 in the Lower Library)

Evaluating shallow geophysical tools on a variety of Scottish archaeological site types.
D Pratt, G Noble, D Cornwell and J O'Driscoll

MESOMAG: A geophysical approach on Mesolithic land use in complex environments.
L Claeys, C Conneller, P Crombe, K Deforce, N Jordanova, M Moucheron, J Pollard, J Verhegge, G Warren and P De Smedt

From hyperbola to context: An analysis of GPR data from a "palace" building at Verulamium.
C Tudinger Charnley, K Lockyear

Assessing geophysical techniques for clandestine graves in peat: A recommendation for the Moors Murder Case
K Thomas McGowan

A haunting in Gumbati: The mystery of a lost Archaemenid palace and detective work with soul magnetism and PXRF measurements to decode a magnetic ghost feature
S Hahn, M Schauer, M Parsi, J Fassbinder and K Kaniuth

Chalk cherries and chairs – Grim's Ditch geophysical survey outreach project
M Guy, L Lawrence and V Guy

Revisiting 25 years of geophysical treasure through a collaboration between community archaeologists and academics
L Benoit, M Szedzielorz, G Anderson, C Dunn, C Harbourne, H Storton, S Woof, A Thompson, J Lewis and M Pisz

Lost in translation – Comparison of magnetometry and earth resistance results from Caldicott, Abingdon
R Ainslie

Use of vegetation indices in rapid archaeological cropmark survey
J Gray

EVALUATING SHALLOW GEOPHYSICAL TOOLS ON A VARIETY OF SCOTTISH ARCHAEOLOGICAL SITE TYPES

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Introduction

We present research, as part of an ongoing PhD, focussed on evaluating single and multiple geophysical techniques to delineate archaeological features in a variety of example site types in Scotland. Our findings show that collecting suites of complementary geophysical data is essential, but in varying ways depending on site conditions and target properties.

Archaeological Sites

Seven sites were selected across Scotland for investigation and comparison, including four tower house complexes (Fraser, Drum, and Dunnottar Castles and the site of Old Balmoral), the Peel of Lumphanan, the Kair Hill Roman marching camp in Aberdeenshire, and the Burghead Pictish fort in Moray. These sites were selected as they are largely under-mapped geophysically but known archaeologically, yet the wealth of new geophysical data collected in this research project positively impacts the ongoing archaeological investigations of each site. The targets, ages, and ground conditions have both similarities and differences, which allows a rigorous assessment of the performance and applicability of the chosen geophysical survey tools.

Geophysical Surveys

Geophysical data have been collected for six sites, including approximately 8 hectares of magnetic gradiometry, twenty-eight 30 x 30-meter grids of shallow resistance, nearly 9 km of ground penetrating radar (GPR). and a few resistivity tomography and seismic refraction/reflection 2D profiles. The geophysical equipment used to collect these data included: 1) GeoScan Research RM85 shallow resistance kit using a twin-electrode array with 3-electrode mobile probe; 2) a SynSys 5-sensor magnetic gradiometry cart; 3) Geoscanners GPR cart with a GCB2040 (200 and 400 MHz) antennae box; and 4) 48-channel Geode seismic reflection/refraction equipment with hammer source, usually with supplementary photogrammetry and/or Lidar data. A Juniper systems GEODE GPS unit and a Leica dGPS was used for positioning/navigation, either cart-mounted or at profile end points. GPR, electrical resistance, and magnetic gradiometry data were acquired at Fraser, Drum, Balmoral, and Dunnottar Castles, with additional seismic data acquired at Castle Fraser. Additional GPR data at specific targets was acquired at Burghead and Kair Hill.

Summary of Findings

Overall, the geophysical surveys detected buried features of interest at each site, with complementary response patterns from different tools interpreted together to identify the structures. Some of these were expected from historic sources, while others were unexpected, and in some cases expected features were not detected.

As an example, one of the unexpected features was the target of a National Trust for Scotland (NTS) excavation which found the predicted feature and led to re-interpretation of a historic map. What had been interpreted as a possible boundary between two fields from what appeared to be a line of trees was a wall not only marking a hard boundary, but also a water barrier. Combining the result from resistivity and magnetic gradiometry had also suggested the wall was of mixed lithology, and the radar response for this and another semi-exposed wall nearby combined to suggest that it was "Rubble-Built" of materials available locally from glacial till. By contrast the radar signature at another location suggests a wall built of dimension stone.

An attempt to confirm the buried location of the boundary ditch at Kair Hill by radar was partially successful, identifiable in two of four parallel and adjacent profiles in one area while completely obscured in another only a few meters away by the presence of a buried cobble floor from a WW II building. The building was present on an old OS map of the area, but there is currently no surface indication it existed.

Preliminary results from the site of Old Balmoral identified several interesting features in the vicinity, but the demolition and removal of the original structures appears to have included even the foundation or raised the possibility that there weren't any.

Challenges and Lessons Learned

Site conditions including the underlying geology consisting of iron-rich igneous bedrock, saturated soils, ground cover and tree canopy-blocked satellite navigation.

Practical lessons learned from the research thus far include that a long lead time can be required for site access permissions, often multiple per site, from the property owner and at times a government agency e.g. National Trust for Scotland (NTS) or Historic Environment Scotland (HES), despite agencies being very cooperative. Data processing and interpretation takes longer than acquisition, especially for GPR. A rapid way to determine any potential structure orientation before designing other profile-based acquisition is to acquire, process and interpret magnetic gradiometry data first. In addition to understanding the potential impact of the underlying geology, the weather, terrain, and limitations from ground cover and tree-canopy cover should be factored into geophysical acquisition plans. Plotting processed geophysical data in multiple ways and using varying colour palettes can reveal hidden information. And finally, a thorough review of prior archaeological and geophysical work is essential, which can be a major challenge if they are unpublished or difficult of access.

MESOMAG: A GEOPHYSICAL APPROACH ON MESOLITHIC LAND USE IN COMPLEX ENVIRONMENTS

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Archaeological prospection for Mesolithic land use is notoriously challenging. Mostly, hunter-gatherer remnants are restricted to lithic artefacts, sometimes complemented with sparse hearths or pits. Generally, field research focuses mainly on hunter-gatherer land use in more accessible areas, characterized by favourable preservation conditions, notably wetlands and coastal regions (Blinkhorn & Milner, 2014). This geographical bias results in the underrepresentation of sites with poorer preservation conditions, or those in less accessible environments. These include mountainous areas and drylands with shallow soils and poor preservation potential. Already challenging in any environment, prospecting for Mesolithic archaeology in such mountain or dryland settings is exacerbated by the challenging landscape conditions. While traditional approaches do allow for the sporadic detection of Mesolithic sites in such complex settings, a structured, systematic prospection approach for tackling these environments does not exist. This contrasts starkly with recent advances in wetland prospection, which has been a boon for Mesolithic landscape archaeology in stratified landscapes (Verhegge et al., 2016).

To mediate this imbalance, the MesoMag project aims to provide a fuller framework for prospection of Mesolithic landscapes in challenging environments. This project is a collaboration between Ghent University, University College Dublin, and the Universities of Southampton and Newcastle, as well as the Bulgarian Academy of Sciences. Starting from the hypothesis that Mesolithic land use is often reflected by fire events (both *in-situ* via hearths and fire pits, as well as across larger areas via intentional burning of vegetation), we explore the potential of magnetic soil characterisation for identifying and mapping hunter-gatherer activity traces. While thermally induced soil magnetic enhancement has long been established (Le Borgne, 1955), more recent research has revealed that the magnetic signal of fire-affected soils can be distinguished from background variations (Jordanova et al., 2018; 2019a; 2019b). This can be achieved by a fuller characterisation of the magnetic mineralogy of fire-affected deposits (combining susceptibility with magnetic remanence characterisation). Building on this research, MesoMag is exploring the potential of characterising pyrogenic magnetic enhancement of archaeological soils, as a proxy for past hunter-gatherer land use. Through intra-site comparison of properties from fire-affected and unaltered soils, the pyrogenic and archaeological signal should be distinguished from background variations. The potential of such an approach hinges on the preservation of the magnetic signal by pedogenic processes over time, such as the progressive oxidation of iron (Jordanova et al., 2019b).

To address this challenge, Mesolithic sites with contrasting soil types are selected; Cherhill, in south-west Engeland, and Chest of Dee in the Cairngorm Highlands of Scotland (Fig. 1). Cherhill is located at the margin of rendzina-dominated drylands and hosts calcareous tufa deposits with a sequence of prehistoric buried soils (Evans et al., 1983). Pedological processes in such soils are primarily controlled by carbonate dissolution, with the soil reaction ranging from alkaline to neutral (Jordanova, 2016). In contrast, soils at Chest of Dee consist of peaty gleyed podzols (Fig. 1; Wickham-Jones et al., 2020), characterized by a thick humic horizon overlying a bleached, weathered eluvial horizon. Beneath this is a dark illuvial horizon enriched with organic material and sesquioxides. The parent material is sandy, and the soil reaction is acidic (Jordanova, 2016). These two soil types contrast in pH and their dominant pedogenic processes, therefore providing strongly opposing conditions for evaluating our methodology. Throughout the project runtime, these key sites are complemented with additional prehistoric hunter-gatherer sites in soil environments with more neutral pH conditions.

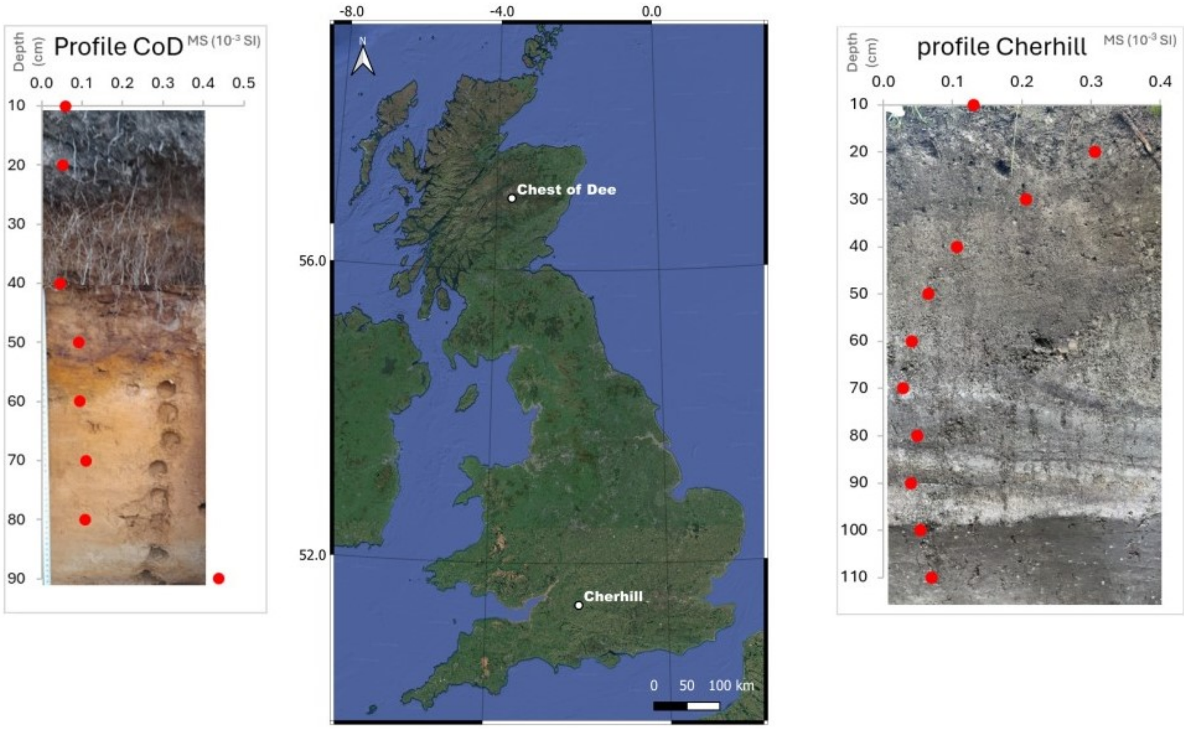

Figure 1: Map of the United Kingdom with the study areas indicated; Cherhill in the south-west of England and Chest of Dee in the Cairngorm Highlands of Scotland. Accompanied by reference profiles from Chest of Dee (CoD) and Cherhill with magnetic susceptibility (MS) – depth graphs

To characterize the properties of aforementioned soils, samples are collected for magnetic analyses. Vertically exposed profiles are continuously sampled in blocks of 2 cm (> 100 g) and processed as described by Walden (1999) and Jordanova (2018). Complementary samples are taken for standard chemical and physical soil analysis to contextualise magnetic analyses. In addition, bulk soil samples are taken for charcoal analysis to allow radiocarbon dating of palaeosols and provide palaeoenvironmental information. *In-situ* collection of soil profile data includes magnetic susceptibility (MS; SM30 - ZH instruments) (Fig. 1) and colour measurements (Nix Pro) at a sampling resolution of ca. 10 cm. This sampling strategy is supplemented by areal geophysics, such as FDEM (Dualem 21s), MAG

(Sensys FGM650) and GPR (SnS pulseEKKO 500 MHz) as appropriate following governing soil conditions.

In total five profiles were sampled at Cherhill, wherefrom three contained evidence of past human activity, and two natural soil profiles showing no anthropogenic disturbances. At Chest of Dee, three profiles with evidence of human activity, and one natural soil profile were collected. Sample pre-processing for magnetic analyses is currently ongoing. Further work will include the interpretation of magnetic signals to characterize the magnetic mineralogy, and juxtapose magnetic and charcoal records to identify and characterise fire events. In later research stages, *in-situ* collected geophysical data will be integrated into forward modelling procedures to guide potential geophysical survey strategies.

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FROM HYPERBOLA TO CONTEXT: AN ANALYSIS OF GPR DATA FROM A 'PALACE' BUILDING AT VERULAMIUM

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Ground-penetrating Radar (GPR) is a geophysical technique which is being used more frequently in recent years for archaeological prospection. Horizontal time-slices and 3D models are increasingly being used for the visualisation and interpretation of this data, with reflection profiles being used less often. This means there are fewer detailed analyses of profiles, with a greater focus on larger-scale surveys which are better visualised through time-slices. This project examined whether a detailed analysis of reflection profiles can lead to a better understanding of the features and stratigraphy of a site. This was applied to a large 'palace' building at the Roman city of Verulamium and surrounding buildings which were surveyed by the Community Archaeology Geophysics Group (CAGG) in 2021-2022 (see Figure 1).

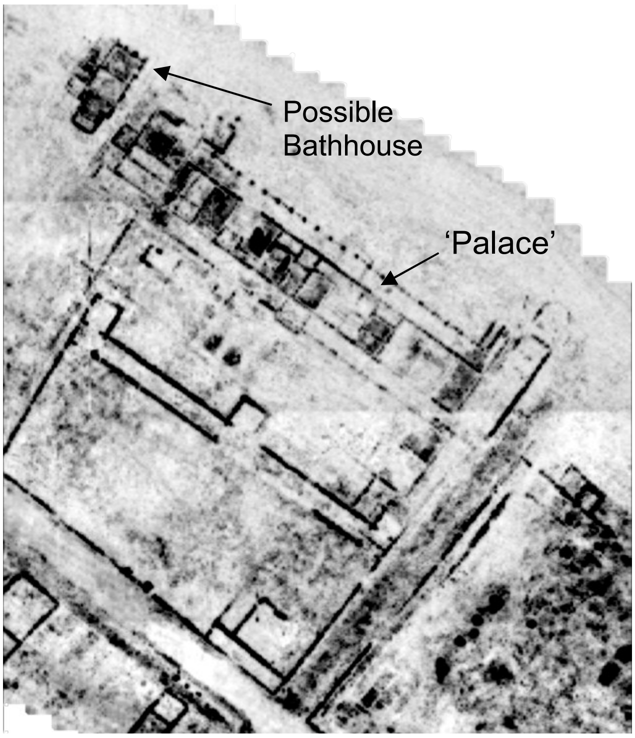

Figure 1: annotated time-slice of the 'palace' building and surrounding buildings (adapted from Lockyear, 2022).

Methods

For each reflection profile, features such as walls and surfaces were identified and mapped onto a time-slice. As well as identifying features, a single-context recording system and Harris Matrix were applied (see Figure 2). These are recording systems which were developed for recording stratigraphic units (contexts) and relationships on excavations. These were used here to understand if the same systems could be used to record and analyse stratigraphy derived from GPR data. Context numbers were assigned to each identified feature and its relationships with other features recorded using a Harris Matrix software. This was then used to analyse the stratigraphic relationships between features and broader chronological relationships between different buildings and areas.

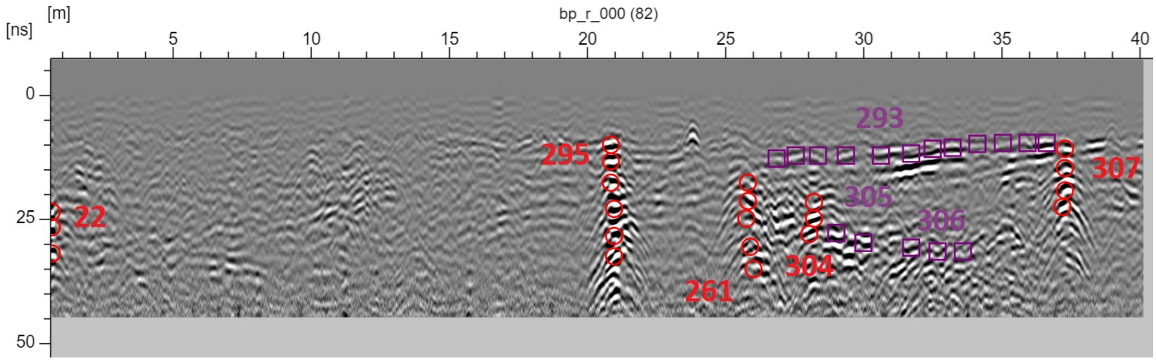

Figure 2: Example of reflection profile with walls (circles) and surfaces (squares) annotated, as well as the assigned context numbers.

Results

Examining the features visible in reflection profiles led to a greater understanding of the features of the 'palace' building and surrounding buildings. Specifically, the functions of different buildings were hypothesised. For example, an ancillary building to the north-west of the 'palace' appeared in the reflection profiles to have short stacks of hyperbolas beneath a hard surface. This was interpreted as a possible hypocaust system, with the hyperbolas reflecting the pilae. The building as a whole was therefore hypothesised to be a private bathhouse, although excavation would be needed to clarify if it had the other features associated with Roman bathhouses.

The analysis of the stratigraphic relationships between features meant the modifications to the buildings over time could be examined and phases were proposed. For example, in the profiles and time-slice there appeared to be intercutting walls. This occurred between a wall of the 'palace' building which cut through a wall of the south-western building. Therefore, this analysis suggested that the colonnaded 'palace' building was built later than the building to the south-west. Overall, three likely phases were proposed: the construction of the south-western building, construction of the colonnaded 'palace' building and post-abandonment (phases 1, 2 and 3 in Table 1). There are additionally three possible phases, which are based on features with uncertain relationships, or a limited number of relationships (see possible phases 1a, 1b and 2a in Table 1).

The use of a single-context recording system and Harris Matrix was important in systematically recording the relationships between features and understanding these changes. Harris' (1989, pp.30-37) method was modified in that contexts which were part of the same feature and contemporary contexts were recorded in the same way (with an '=' sign). This resulted in a fairly flat matrix, but was important in understanding which features were contemporary and assigning them to phases. However, the technique may need to be refined further for use with GPR data since there were some inconsistencies within the matrix.

Phases	Description	Relative Dating	Absolute Dating?	Main Features
Possible Phase 1a	Pre-Palace	Earlier than Phase 1, Maybe before the Antonine Fire	Maybe before 155 CE	Pit (331)? Ditch (91)? Walls (141 and 144)?
Phase 1	Construction: SW Building, Middle Section	Probably later than the Antonine Fire	Later than 155 CE	Most features in south-western building and middle section
Possible Phase 1b	SW building adaptation	Later than Phase 1	Unknown	Wall 830 Central room/corridor?
Phase 2	Construction: North-eastern building (and bathhouse?)	Later than Phase 1, probably earlier than the town wall	Early-mid 3rd century CE? (Following Frere, 1983:49-53)	Most features in north-eastern building
Possible Phase 2a	NE building adaptation (and bathhouse construction?)	Later than Phase 2	Unknown	Surface 348 Surface 419 'Western Extension' of north-eastern building?
Phase 3	Post-abandonment	Later than Phase 2, Maybe after construction of Town Wall	Late 3rd – early 4th century CE? (Following Frere, 1983:49-53)	Surface 427

Table 1: Table of proposed phases with main phases unshaded and possible phases shaded.

Discussion and Conclusion

This project has used a detailed analysis of reflection profiles to better understand a group of buildings at Verulamium. The scale of the buildings and high-status features they contain (such as a hypocaust system) reinforces the initial suggestion that this was an elite residence. This is congruent with existing evidence of the building of large private buildings following the widespread destruction caused by the Antonine fire (Niblett, 2001, pp.112-113). The examination of stratigraphic relationships has led to an initial understanding of the different phases of building and occupation and how the buildings were added to and modified over time. These results have demonstrated the utility of reflection profiles for understanding stratigraphic relationships in particular. Furthermore, the application of a single-context recording system and Harris Matrix has suggested this may be a useful way to systematically record and interpret stratigraphic relationships derived from GPR data.

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ASSESSING GEOPHYSICAL TECHNIQUES FOR CLANDESTINE GRAVES IN PEAT: A RECOMMENDATION FOR THE MOORS MURDERS CASE

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Introduction

The literature surrounding the topic of "detecting clandestine graves within a peat environment" is severely lacking therefore, the current research set out to assess a number of geophysical techniques in order to ascertain the optimum technique to incorporate in the search for clandestine burials in the geological environment of peat. The basis for this research involves the murder of five victims, whose ages ranged from 10 to 17 years of age. One of these victims, Keith Bennet is still unrecovered and suspected of being buried on Saddleworth moors. Now, the case of the moors murder is still considered active, to this effect the research did not take place on Saddleworth moor. Instead, the research was conducted 28km north of Saddleworth moor, within a field facility owned by the university of Bradford. The facility contained a topography similar to Saddleworth moors, the superficial deposits were identified to be peat with a bedrock deposit of sandstone grit.

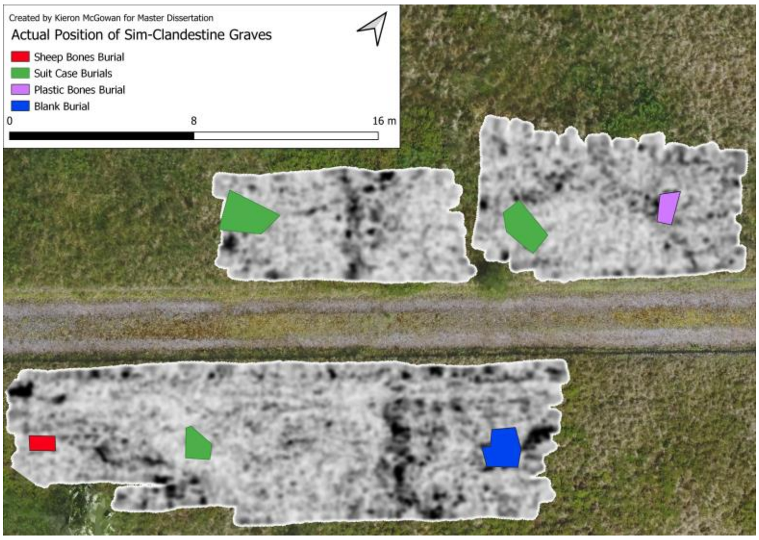

Figure 1: 3DGPR Data, showing actual positions of simulated clandestine graves and georeferenced in QGIS, Source: Author

Materials

A total of three techniques were assessed to provide a conclusion for the optimum technique, auger bedrock probing, with a Trimble GNSS R12i to record the probed locations, magnetometry with a Bartington Grad601, electrical resistivity tomography with Guideline Geo ABEM terra meter LS2, and MÄLA Mira 3D compact GPR in tandem with a Carlson BRX7 GNSS rover and base station. Although no results were collected for the technique of electrical resistivity tomography due to technical difficulties. These techniques were used to survey the known locations of four simulated clandestine burial types, three suitcases filled with sand and buried with a series of metal and non-metal items, sheep bones arranged in the size and shape of a 12-year-old in a supine position, resin bones also arranged in the shape of a 12-year-old that was in a supine position and an empty burial to act as a control. These simulated clandestine graves were spaced irregularly within a 40x20m survey area of the field facility. A total of 6 target models were created, three on either side of the service road that runs through the survey area, these positions can be seen in figure 1.

Processing

A number of techniques were used to process the different data types collected from the geophysical equipment used. The auger data was processed by recording the depth and positions of the auger samples onto the Trimble GNSS R12i. this data was then imported into QGIS to create a QGIS. The magnetometry data was processed through the use of Geoplot and was then hand georeferenced within QGIS. The 3D GPR data was processed in three stages within the WAVE programme, filtration, background removal and establishment of the magnetic wave velocity. Once processed, the slices were reviewed, and the ones that were interpreted to show the known positions of the target burials were imported into QGIS.

Results

The results of the research found that the magnetometry data was extremely stagged, this is thought to be due to the uneven and overgrown state of the survey area. The Auger probing found that the bedrock depth within the field facility was greatly varied. The results of the 3D ground penetrating radar were found to be the only results that could make out the known positions of the simulated clandestine burials. The known burial positions were interpreted at a number of different depths. The target burials that consistently showed within the 3D GPR data was found to be the suitcase burials. The grave cut of the sheep bone burial was the next consistently interpreted position found within the 3D GPR data.

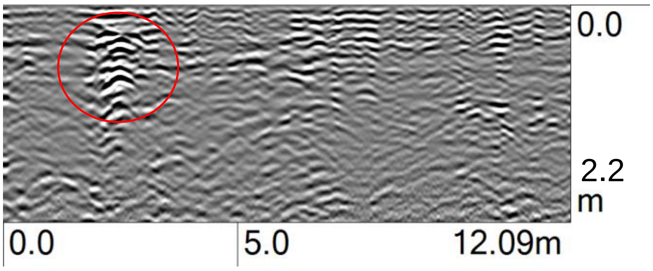

Figure 2 – 3DGPR Radargram of a single suitcase burial (Circled), Source: Author

Conclusion

In conclusion, this research assessed the techniques of Auger bedrock probing, magnetometry and 3D GPR for their reliability in the search for clandestine graves. The research found that the use of auger probing to narrow down the survey area is a viable technique although it does take time to collect the data. Magnetometry is highly reliant upon the target victim being buried with ferrous objects and the area that they are buried in is not full of noise. ERT was found to only be useful if the suspected clandestine grave location is known to the surveyor. It was found that the most optimum technique was the 3DGPR, however, this equipment needed to be used and data processed by a trained professional and even then, the interpretation of the data is based off of the anomalies, and therefore a definitive answer cannot be given until the suspected clandestine grave has been excavated. In relation to the moors murders, it can be concluded that the 3DGPR should be used for any future investigations that may be conducted, however the survey area will need to be prepared to allow for optimum results.

A HAUNTING IN GUMBATI: THE MYSTERY OF A LOST ARCHAEMENID PALACE AND DETECTIVE WORK WITH SOIL MAGNETISM AND PXRF MEASUREMENTS TO DECODE A MAGNETIC GHOST FEATURE

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Founded by Cyros II. in 550 BC, the Archaemenid empire, also known as the First Persian Empire, was the largest empire by that point in history, stretching at its largest territorial extent from the Balkans and Egypt to the Indus Valley, including Southeast Europe and Central Asia, with West Asia as the base. In 330 BC, Alexander the Great conquered the Achaemenid Empire, marking a key achievement in the campaign of his Macedonian Empire.

While it is known that the empire was divided into twenty to thirty provinces or satrapies for administrative purposes, it is unclear how the empire was organised at its borders and how it interacted with its neighbours. One of the borders ran presumably through the Alasani plane south to the Greater Kaukasus, the area of today's Georgia and Azerbaijan.

During an emergency dig in 1978, at the site of Gumbati, east of Georgia, at the edge of the Alasani plane, architectural fragments with Achaemenid influence were unearthed. From 1994 to 1996, further excavations were conducted at this site located at the periphery of the Achaemenid empire, revealing a mudbrick building with architectural similarities of its ground plan to the complexes of Sari Tepe (Azerbaijan), Benjamin (Armenia), Persepolis and Susa (Iran). However, small finds, especially the pottery, are almost exclusively of local origin.

Acknowledging the unique potential of the site, investigations were resumed in 2018, including geophysical prospection techniques, as the precise geographical location of the mid-90s excavation was only roughly known and intense agricultural activity over the two decades had obliterated all traces of the trenches. Magnetometer carried out with two Caesium total-field magnetometers in duo-sensor configuration - a Scintrex Smartmag SM4G- special magnetometer and a Geometrics G-858 magnetometer – and a vector gradiometer - a Foerster Ferex instrument. The survey areas were divided into 40 m by 40 m grid squares and subdivided into adjacent segments, each measured by a different device. The sensors of each instrument were carried circa 30 cm above the ground. With a sensor distance of 0.5 m for each instrument, a line spacing of 1 m and a continuous measurement at a frequency of 10 Hz, we obtained a data resolution of at least 0.1 m by 0.5m.

The resulting magnetogram revealed a poorly preserved site, adversely affected by deep ploughing and contamination with small metal pieces from agricultural cultivation. However, the tracing of the building complex was inconclusive. Only an ambiguous linear feature sparked the archaeologists' interest. It is somewhat contradictory that these features run parallel or perpendicular to the modern plough lines. The presence of an anomalous body was suspected to be a mudbrick wall, which was supported by the results of the electromagnetic induction (EMI) (Thiessen et al. 2020).

The subsequent 2019 excavations, unfortunately, did not yield any archaeological or other findings at the location of the anomaly, leaving the source of the anomaly unexplained. We were now left with two riddles: Where is the Achaemenid palace, and how can the detected anomaly be explained?

The latter is another example of a "ghost feature": a registered anomaly in geophysical data whose origin is not visible based on colour and texture differences in archaeological excavations. To demystify this feature, soil samples were collected along vertical profiles in 10 cm increments in the open trenches at and around the anomaly's supposed location to unravel the anomaly's nature. We studied the samples' magnetic properties, including susceptibility measurements accompanied by pXRF (Portable X-ray fluorescence) measurements, to identify variations in magnetic mineralogy and magnetic properties in correlation with the soil chemistry.

The measurements revealed that the anomaly is likely caused by the two to three times higher susceptibility at around 35 cm depth right at the edge of the plough horizon, continuing through the 40 cm thick plough horizon. The increased values correlate with an increase in elements, which indicates human activity, especially calcium and phosphorus, which are also indicators of the presence of fertilizer. The forward modelling of the susceptibility data and the generation of artificial magnetograms suggest that an enhanced layer of 2-3 cm of a width of 2.5 m is sufficient to cause a magnetic contrast of around 5 nT, explaining why the "ghost feature" can be detected.

With new access to old satellite images recorded during the dig in 1994, we realized that the magnetometer survey area indeed covered the excavation trenches. Finally, we can conclude that this „ghost feature“ does not belong to the Achaemenid building complex and is not an outer wall or enceinte given its diverging orientation. Unfortunately, this also implies that the building complex is not preserved in a way detectable by magnetometer prospection. Until the dispute with the land owner is not settled, the question of how much of the ‘palace’ is still present will remain unanswered, as will what truly caused the “ghost feature.”

Luckily, the dispute led to a change of plans for the campaign, resulting to the discovery of another monumental Achaemenid complex just 2.5 km north of Gumbati with a representative hall with six in-situ bell-shaped column bases (Fassbinder et al. 2021, Kaniuth 2022).

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CHALK CHERRIES AND CHAIRS – GRIM'S DITCH GEOPHYSICAL SURVEY OUTREACH PROJECT

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In 2019, the Chilterns National Landscape team launched The Chalk, Cherries and Chairs Landscape Partnership Scheme (CCC), funded primarily by the National Lottery Heritage Fund and the HS2 Community and Environment Fund. One of the projects within CCC explored 'The Mystery of Grim's Ditch'. Its aim was to uncover the secrets of this ancient earthwork across the Central Chilterns, Buckinghamshire, where it is a designated Scheduled Monument. The project engaged with residents of and visitors to the Chilterns through a number of events and activities, including a geophysical survey with Aylesbury Young Archaeologists Club (YAC), Chiltern YAC and Buckinghamshire New Shoots.

Grim's Ditch is a series of discontinuous linear earthworks believed to date to the Iron Age, and extends across the Chilterns from Bradenham to Berkhamsted, and into both Hertfordshire and Oxfordshire. In Buckinghamshire, the earthworks mainly consist of a single bank and ditch, with the bank on the north side of the ditch (Buckinghamshire County Museum Archaeological Service 1997,1).

The LiDAR data gathered as part of Chiltern Conservation Board's "Beacons of the Past" Project and from the Environment Agency (2017) indicated a slight linear feature, along with field boundaries, which may suggest the earthwork continued across the Missenden Valley, north of Road Farm (centred at SP 88150 02941), and beyond the surviving ditch and bank earthworks (Fig. 1).

In 2021 AOC Archaeology Group was commissioned to undertake magnetic gradiometer survey and an earth resistance survey in the fields to the west of Road Farm, Great Missenden. The gradiometer survey identified a number of linear magnetic responses, of which two responses align with the prominent section of the Grim's Ditch earth work to the north-east at Hunts Green. The earth resistance survey focused on this area and identified a corresponding linear anomaly which interestingly corresponded with a linear feature present on the LiDAR coverage. The AOC survey raised even more questions, and further surveys were clearly needed.

Earlier in the project, both branches of the Buckinghamshire Young Archaeologists Club had been visited by Lucy Lawrence, where information about Grim's Ditch was shared, and discussions lead by YAC members raised questions about the potential purpose and function of the monument. Based on the success of these sessions, it was suggested an open survey weekend could be undertaken, offering young people the opportunity to carry out the geophysical survey themselves. On this basis, the CCC partnership invited the Aylesbury and Chiltern branches of YAC, along with the Buckinghamshire New Shoots participants (another CCC initiative teaching practical conservation skills to young people aged 14–18), to undertake the geophysical survey.

The surveys were carried out over two days on the 16th and 17th of September 2023 with instruction and supervision by competent operators and archaeologists. The aims were as follows:

- Gather further evidence for the presence of Grim’s Ditch in this location;
- Evaluate the effectiveness of four different geophysical methods;
- Introduce the different geophysical techniques to a new audience

To compliment the work previously undertaken, the survey was focussed on the area of the AOC Archaeology Group surveys where the anomaly had been detected. The geophysical methods utilised included;

- One hectare (ha) Frequency Domain Electromagnetics (FDEM);
- Four Electrical Resistivity Imaging (ERI) profiles;
- Eleven Ground Penetrating Radar (GPR) profiles;
- Nine Transient Electromagnetics (TEM) profiles

The FDEM results were dominated by the presence of medieval ridge and furrow (Fig. 2), on a similar alignment to the projected path of Grim’s Ditch. However, this anomaly was only present in the north-east half of the survey area and could not confidently be considered to be part of the monument, solely from these results alone. The FDEM data were inverted to determine if the response from Grim’s Ditch could be enhanced by constraining the geological interface. Unfortunately, the results were not overwhelmingly successful.

The results of the Electrical Resistivity Imaging survey confirmed the presence of a substantial *c.*10–14m wide ditch cut which followed the projected path of Grim's Ditch and cut into the chalk bedrock (Fig.3). The survey also identified the ditch extending a further *c.*110m to the south-west into the neighbouring field, which was not previously known.

One of the 300MHz (central frequency) GPR profiles presented a clear reflection inside the ditch which could represent either backfilling in two separate phases, or that the ditch was recut, representing maintenance or reuse of the boundary (Fig.3).

The portable TEM system used within this study was able to resolve the width and depth of the ditch cut, due to the ditch clearly cutting into the bedrock (Fig.3). In such an instance TEM could be an alternative to FDEM or ERI, considering the scale of the moment.

The team would like to express our gratitude to The Chalk, Cherries and Chairs Landscape Partnership Scheme for the opportunity to contribute to the Mystery of Grim’s Ditch Project, Road Farm Countryways for access to the site and facilities at the farm, and the assistance of YAC members and leaders, and Buckinghamshire New Shoots members and leaders for their hard work acquiring the data.

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REVISITING 25 YEARS OF GEOPHYSICAL TREASURE THROUGH A COLLABORATION BETWEEN COMMUNITY ARCHAEOLOGISTS AND ACADEMICS

Lucy Benoit[1], Michał Szędzielorz[1], Grace Anderson[1], Colin Dunn[1], Cara Harbourne[1], Hannah Storton[1], Stephanie Woof[1], Albert Thompson[2], Jodie Lewis[1] and Michał Pisz[1]

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Introduction

The application of geophysical methods for archaeological research can be traced back to at least as far as 1938, when Malamphy performed a survey of Bruton Parish Church at Williamsberg. Since then, archaeological geophysics developed into an important part of the discipline (Gaffney and Gater 2003, 13-14). In England, beyond research and commercial use, many community and volunteer organizations actively engage with geophysics and are highly productive. Some operate independently, while others form partnerships (Parker et. al. 2024).

Inspiring community efforts

Despite the impressive amount of data acquired by such community groups accumulated over many years of work, much of it remains unpublished. There is huge potential to work on this data and for public engagement within the field of archaeological geophysics. Building bridges between community groups and academics should be encouraged for the discipline's development and could be inspired by similar initiatives. For example, surveys conducted at Verulamium (Hertfordshire, UK), involved community archaeologists in making significant contributions and archaeological discoveries, funded by the Arts and Humanities Research Council (Lockyear and Shlasko 2015). Successfully merging those two worlds may yet encourage new developments, reminiscent of the shift from research towards teaching of archaeological geophysics in 1970s Britain (Gaffney and Gater 2003, 19-20).

Local Expertise

The community-based ALERT "Archaeological Landscapes' Extreme Research Team" was founded by John Matthews and Jack Foord as an offshoot of CHERT (Charterhouse Environs Research Team founded by Vince Russet, the Heritage Environment Lead for North Somerset Council). Albert Thompson joined the team in 1999 on his retirement from the Royal Navy. His curiosity about Priddy was aroused, particularly of any signs of the village's existence from the late Roman to the early Medieval periods. In order to interrogate the landscape for evidence and clues, he enrolled to study part-time for a degree in Archaeological Studies at the University of Bristol and graduated in 2005. The ALERT group meet on a weekly basis and over the last 25 years have conducted Earth Resistance and Magnetometer surveys of most of the Mendip landscape. Some of this data has been published, but the group wish to ensure that the remainder of this data enters the national archaeological record, thanks to the University of Bradford collaboration. ALERT provides a unique contribution to archaeological research due to their familiarity with local landscapes, their ability to quickly mobilise resources, and their dedication to long-term projects.

Figure 1: John Matthews and Jack Foord, Founder Members of ALERT, Conducting a Resistivity Survey at Charterhouse in 2005

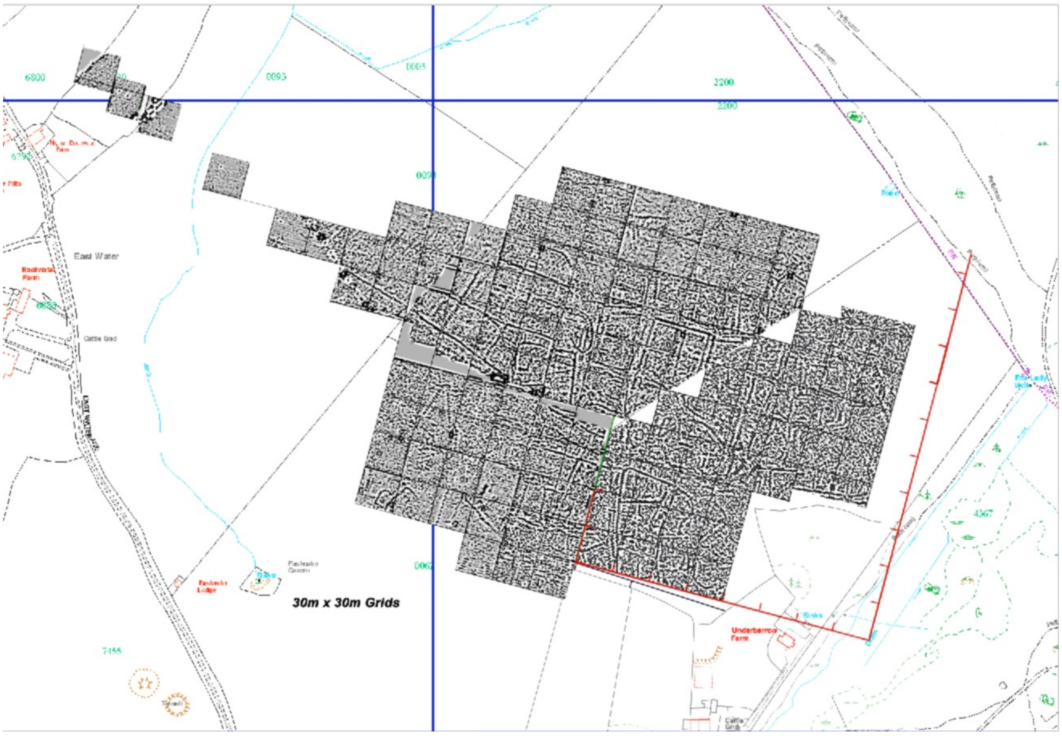

Figure 2: Survey results as produced by ALERT

Student Initiatives

The newly founded student research society Geophysics Students Bradford (GSB[1]) started an extracurricular project, planning to reprocess, revisualise and georeference those datasets in order to develop students' skills and gain experience in archaeo- geophysics. Another aim of the GSB research society is to continue the close collaboration between ALERT and the University of Bradford School of Archaeological and Forensic Sciences and to help ensure this important data is not lost.

Figure 3: Cara Harbourne using a magnetometer as part of the fieldwork training from the University of Bradford in Priddy

A Match made in the Mendips

The Mendip Hills National Landscape (formerly known as an Area of Outstanding Natural Beauty) is an archaeologically rich landscape which has evidence for human activity going back half a million years. Mesolithic, Neolithic, Bronze Age, Iron Age and Roman remains are found in the area around Priddy, such as the Priddy Circles and the impressive Nine Barrows on North Hill. Extensive prehistoric animal and human remains have also been found in the caves in this area. There is substantial mineral extraction, particularly lead, from the Roman period onwards (Lewis, 2011). Investigations of archaeological sites in the area have been carried out by the University of Worcester and the University of Bradford led by Dr Jodie Lewis. Locals and community groups, including ALERT have provided invaluable assistance in identifying and accessing potential sites and providing geophysical data. They have also provided support and encouragement for the archaeological investigations and worked in partnership on field projects. The presented poster will highlight the potential and benefits of a collaboration between a dedicated volunteer group from Somerset and undergraduate students from the University of Bradford. This work was made possible through long-standing collaboration and friendship between ALERT and the leader of archaeological research in Mendip, Dr Jodie Lewis, and the support of University of Bradford teaching staff. [1]The student research society name GSB is a tribute to a long-lasting tradition and legacy of archaeo-geophysical practice in Bradford. It refers to, and honours the first commercial archaeo-geophysical company, Geophysical Services Bradford, founded by John Gater and Chris Gaffney.

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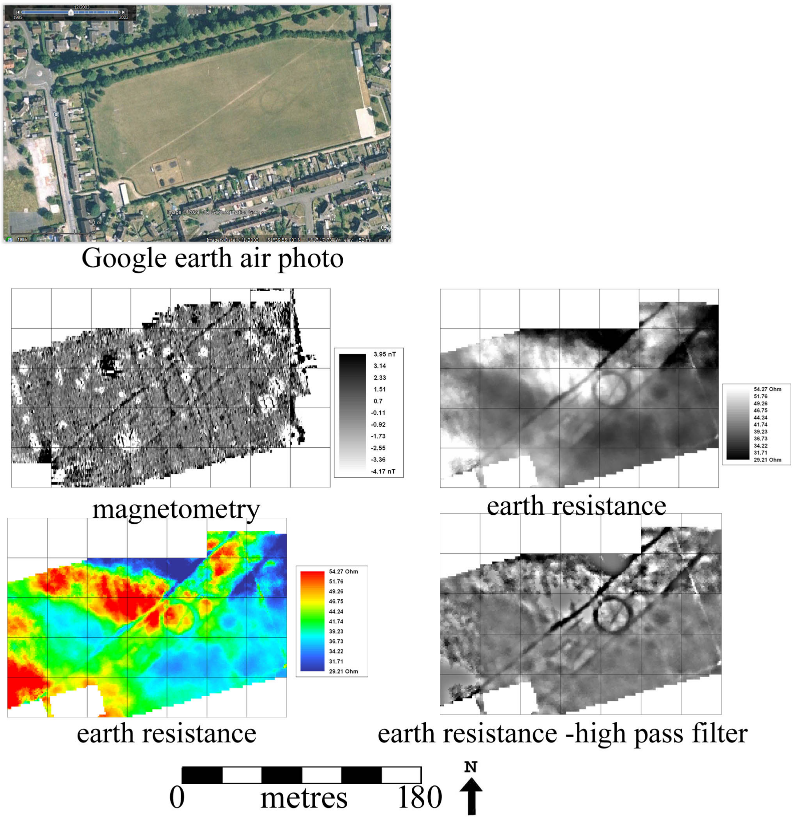
LOST IN TRANSLATION – COMPARISON OF MAGNETOMETRY AND EARTH RESISTANCE RESULTS FROM CALDICOTT, ABINGDON.

Roger Ainslie[(1)],
[(1)]*4 Sutton Close, Abingdon, Oxon, UK*
contact.archgeophys@hotmail.co.uk

This poster for the NSGG 2024 London conference will present earth resistance and magnetometry results from this ongoing research project.



Earth resistance carried over a lengthy period involves differing ground conditions. Whilst the variations can be partially addressed in the data processing, some things become less visible.
This may be of some importance to people looking at surveys as part of the planning process as they are often hurriedly looking at large areas of survey.
It is suggested that requiring a plot with a high pass filtered version of the data may be the best practicable way of minimising this problem.

This may be included in next year's version of my annual survey of English archaeology. [1]

1 Ainslie, R *Archaeology - in the Service of Property Development?* https://archgeophys.weebly.com/

USE OF VEGETATION INDICES IN RAPID ARCHAEOLOGICAL CROPMARK SURVEY

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In the wet and windy year of 2024, a number of UAV based surveys were conducted using an off-the-shelf UAV platform equipped with multispectral sensors, to evaluate the platform's usefulness in rapid survey of cropmarks. The data gathered was used to produce Vegetation Indices (VI) using open-source mapping software. Three sites were covered in South Yorkshire, Derbyshire and Lincolnshire and the resulting observations compared to existing archaeological datasets, including HE AI&M data and a magnetic survey.

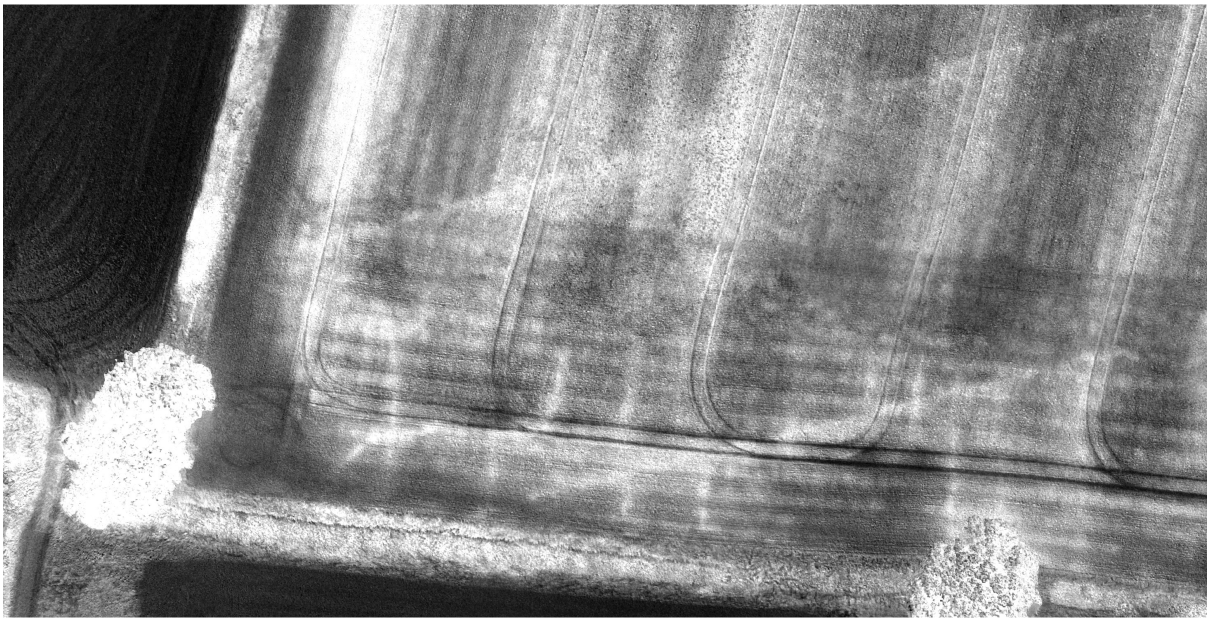

Figure 1. Portion of NDRE VI showing cropmarks of potential Archaeological origin

Background

Many VI have been developed as a means to detect stress in agricultural crops. They highlight stress conditions by manipulating the reflectance values of different wavelengths of light in the visible and near infrared spectra, which vary due to differing levels of chlorophyll in plants (Ray, 1994). It is these same stress conditions that can produce cropmarks, a long established means of detecting buried archaeological features (Wilson, 2000). The use of multispectral data in detecting cropmark features has been an area of growing interest, and a number of studies have shown the use of VI a promising method to enhance the output and aid visualisation of cropmarks (Verhoeven and Doneus, 2011; Bennett et al., 2012; James et al., 2020).

The Survey

Undertaken as an MA Landscape Archaeology dissertation project, this study used a DJI Mavic 3 Multispectral (M3M) UAV, and photogrammetry mapping software OpenDroneMap (ODM) to produce RGB orthophotos and orthophotos of a selection of better performing VI pointed to in the previous studies. The three sites gave an opportunity to test this method over a range of geologies, from the siltstones and sandstones of the Pennine Upper Coal Measures in South Yorkshire, through the limestone and mudstone of the Upper Lincolnshire Limestone, to the sands and gravels of the Trent Valley Washlands. A number of arable crops were covered including some not traditionally known to produce cropmarks readily.

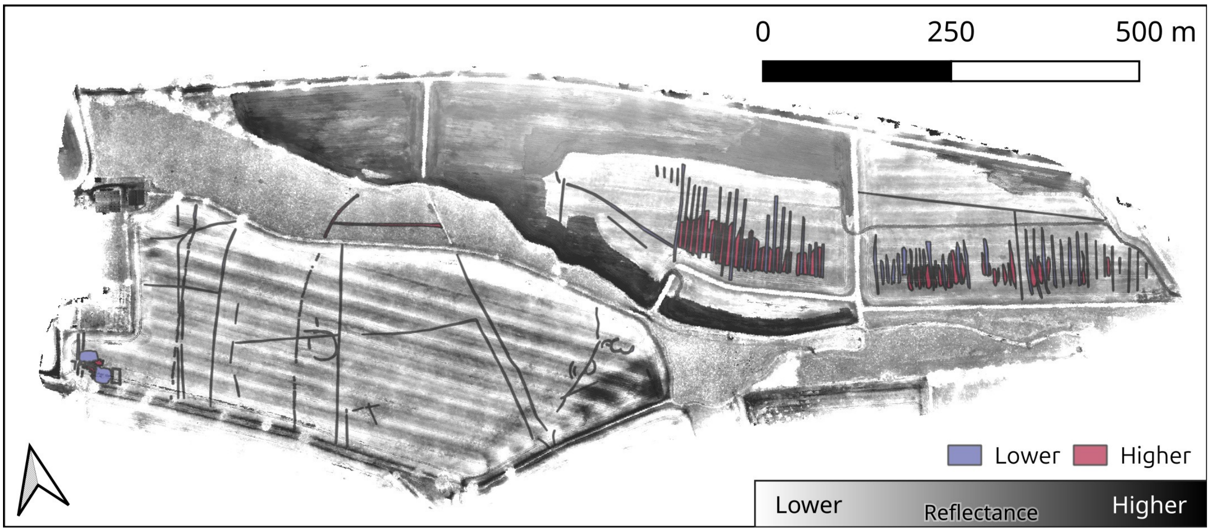

Figure 2. Interpretation of potential archaeological features of higher and lower reflectance overlaid an NDRE orthophoto of a survey area near Arleston, Derbyshire.

Results

Despite its relatively low cost, and the restrictions imposed by the inclement UK weather conditions, the M3M proved to be a capable platform, covering potentially large areas - a total area of 4.8km² was surveyed across approximately four days. When processed by ODM, the data produced was of a quality and resolution that proved useful in identifying cropmark features, even though 2024 was not a good year for cropmarks generally. Where cropmarks did form, they did not form strongly, the wet soil conditions not producing the levels of stress in the crops required. All the VI revealed more cropmarks than the RGB imagery, with two, NDRE and MNLI proving some more detail than the others Some interesting results were observed on crops that aren't usually thought of as producing cropmarks. Some limited crop mark features w bean, OSR and beet crops,, that could be investigated further.

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Figure 1: MALÅ MIRA HDR multichannel 3D GPR array

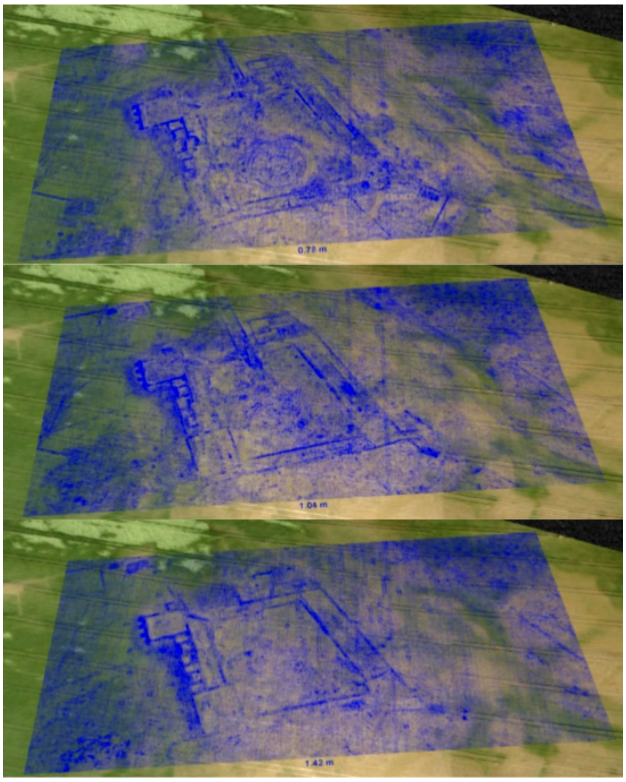

Figure 2: MALÅ GPR data from over a Gladiator training camp (courtesy of Ludwig Boltzmann Institute).

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

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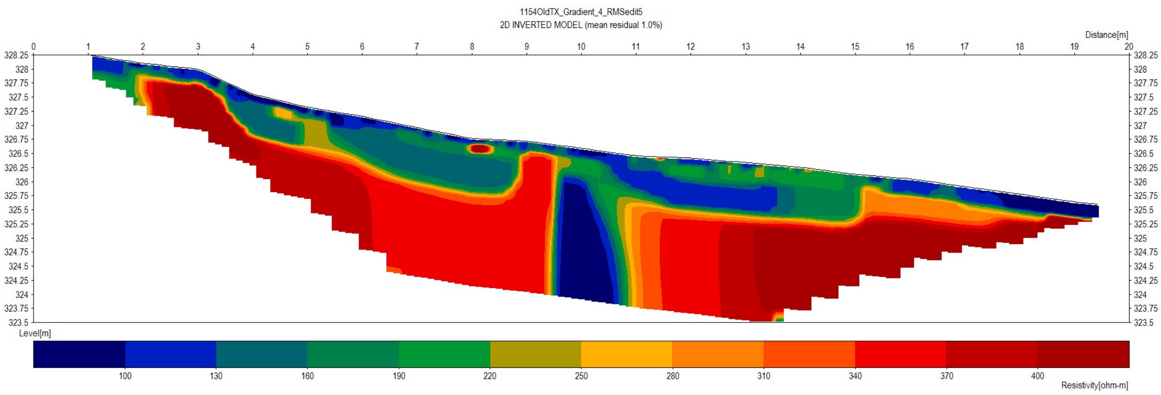

Figure 4: ABEM Terrameter LS resistivity survey over the site of historical mining works.

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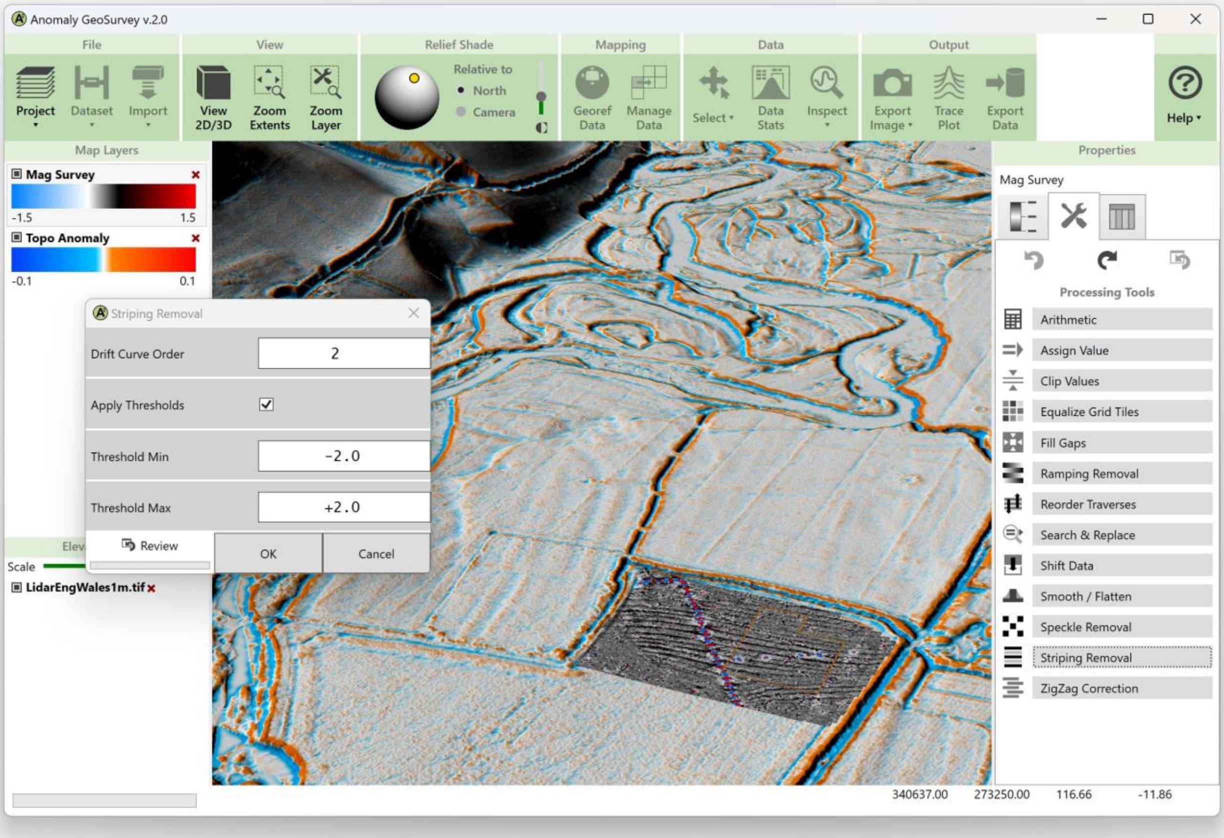

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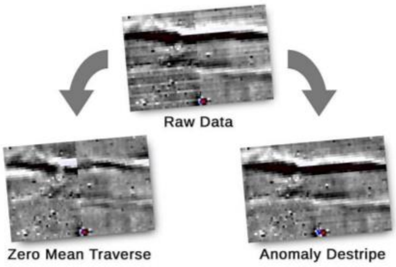

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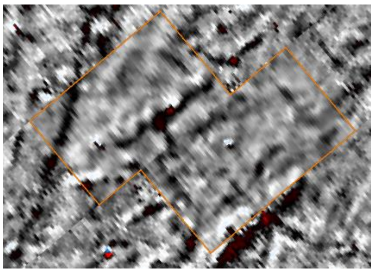
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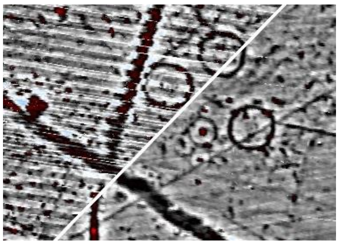
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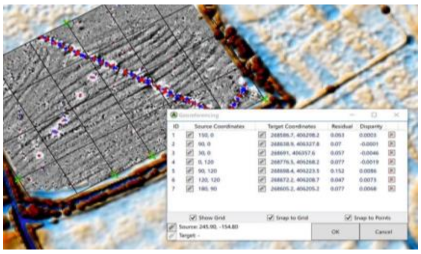
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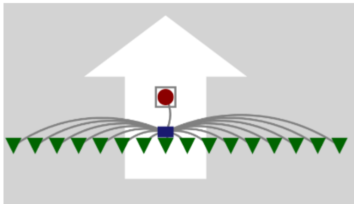
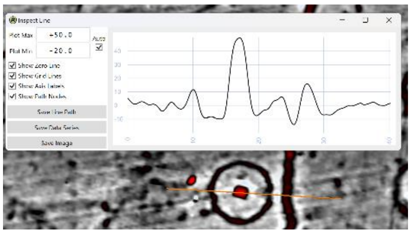

Assemble track data from GNSS path,
sensor time series & cart geometry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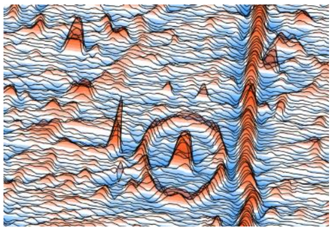
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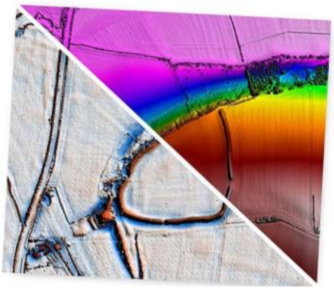
Terrain processing and visualization


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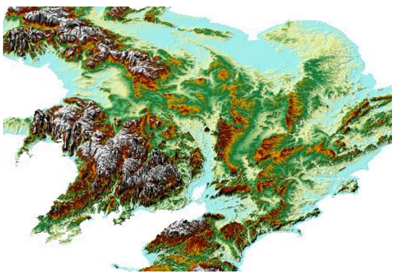
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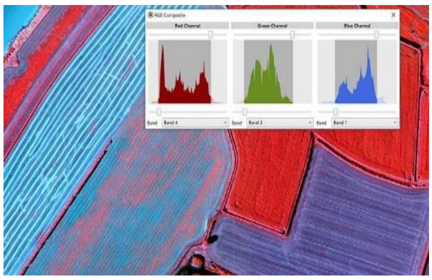
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