On a Commercial Scale – Archaeological Geophysics in England

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Abstract Geophysical prospection for archaeology was first trialled in England over 75 years ago and, as the profession has matured, a dedicated research community has developed in the country. For over 30 years, archaeological geophysics has played a major role in developer-funded archaeology. Whilst no official figures exist for active archaeo-geophysicists in England, it is likely that the number of practitioners is in the 100s, and is perhaps one of the largest communities worldwide. Standards and Guidance are available to support the profession, but it is a challenge for these to keep pace with advancements in technology and methodologies. The balance between improving cost effectiveness, mainly through increased speed of field data acquisition, whilst maintaining research to increase the level of information gained by such investigations remains an important question for both the commercial and academic archaeological sectors.

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C. Cuenca-Garcia et al. (eds.), *World Archaeo-Geophysics*, One World Archaeology, https://doi.org/10.1007/978-3-031-57900-4_8

1 Introduction

1.1 Preface

Archaeological geophysics has been practised in England for over 75 years, with possibly the first recorded survey undertaken in 1946 (Clark, 1996). For over 30 years it has played a major role in developer-funded archaeology, especially at the pre-determination stage of planning applications, as part of the Environmental Impact Assessment process, and in Scheduled Monument Consent applications.

Whilst not currently a statutory requirement, the continuing commitment to best practice within the UK archaeological sector would suggest that, in general, a geophysical survey should be considered a standard part of the overall strategy, where appropriate, for archaeological investigation. However, standard recommendations and requirements currently vary between the regions for a variety of reasons, including regional research frameworks and the perceived efficacy of geophysical survey over different geologies and soils.

This overview aims to introduce how geophysical survey was established in England within the archaeological sector, and its development, present use, and potential for future innovation. Please note that this overview necessarily has a commercial focus as the majority of geophysical survey undertaken in England is carried out within the commercial archaeological sector.

1.2 Limitations

This overview is far from exhaustive and only the most common terrestrial geophysical techniques are discussed. Since the end of the Archaeological Investigations Project (AIP), which collated data between 1990 and 2010 (Darvill et al., 2019), it has become increasingly difficult to estimate the amount of geophysical work being undertaken in England annually. Estimates of current activity could be drawn from the number of projects deposited on openly accessible archives. This would be likely to underrepresent the full extent of geophysical survey work in progress, due to the number of surveys undertaken at early stages of the design/feasibility process and prior to planning application.

Where possible, the text has been designed to be accessible to all those with an interest in archaeology, for further technical detail please consult the reference materials.

1.3 Requirements, Standards and Guidance

The current requirement for archaeological investigation during the planning process in England is laid out in National Planning Policy Framework 2012 (NPPF) as "developers to submit an appropriate desk-based assessment (DBA) and, where necessary, a field evaluation" (NPPF, 2021). There is no specific statutory requirement to undertake geophysical survey, although it may be specified as a requirement in a planning condition issued by a local planning authority (LPA) or government agency. Some authorities have navigated the issue of archaeological geophysical surveys being undertaken pre-application, and therefore potentially without their knowledge or advice, by publishing their own specific requirements, for example magnetic surveys in Norfolk should conform to sub metre traverse intervals and request cart-based survey unless "site conditions prevent the use" (Robertson et al., 2018). Buckinghamshire Council Archaeology Service (BCAS) have similarly published a generic brief for archaeological geophysical survey, which again suggests that cart-based magnetometer survey should be undertaken with traverses at less than a metre (BCAS, 2021). Such guidance may lead to a reduction in active management for Local Planning Authorities (LPAs); a benefit given that currently, all regulatory models in the UK are under resourced (Belford, 2021). Unfortunately, there is currently no central register for county- specific requirements.

The Chartered Institute for Archaeologists (CIfA) identifies the archaeological sector in England as a self-regulating industry. CIfA was originally conceived of in 1973, but only formally established in 1982 as the Institute of Field Archaeologists. In 1986, the Institute passed a resolution that the use of 'paid volunteers' was directly contrary to the 'highest standards of ethical and responsible behaviour' as set out in its Code of Conduct (Hinton, 2011; CIfA, 2014a), far in advance of the publication of PPG 16 in 1990 which brought another level of professionalism to commercial archaeology with the 'polluter pays' principle, followed by the implementation of the Valletta convention in 1995 (European Convention on the Protection of the Archaeological Heritage, 1992). By 1999 the Institute had set out a suite of grades of accredited membership to demonstrate professional competency and associated minimum salaries. In recognition of the broad range of disciplines within archaeology, CIfA was renamed as the Institute for Archaeologists in 2008, and attained a Royal Charter in 2014, demonstrating professionalism in line with other occupations (Hinton, 2011).

There is however no legislative requirement for an archaeologist or archaeological organisation to be a member of CIfA. CIfA's *Standard and Guidance for Archaeological Geophysical Survey* (2014a), whilst not a statutory requirement, is accepted by all individual members and Registered Organisations (ROs). The Standard is also a commonly stipulated requirement in a brief or contract. The Standard states that a geophysical survey will "determine as far as is reasonably possible, the nature of the detectable archaeological resource within a specified area using appropriate methods and practices" which allows for broad practice to reflect the versatility of archaeological prospection. This guidance is primarily designed for the planning process but covers all geophysical survey within archaeology. It includes geophysical survey in terrestrial, marine and inter-tidal environments but retains a predominately terrestrial focus. The level of detail within the CIfA guidelines is appropriate for project management but does not include technical specifications. It was originally written with a U.K. focus, but as CIfA is now an international institution this will be addressed in the current review of the guidance.

Most geophysical procedural methodologies in England originate with the comprehensive Geophysical Survey in Archaeological Field Evaluation. First published by English Heritage in 1995 and comprehensively revised in 2008 (English Heritage, 1995, David et al., 2008), it was transferred over to Historic England in 2015 when the Arm's Length Government Body was separated from the now-charitable English Heritage Trust. The European Archaeological Council (EAC) guidance is considered to supersede the Historic England guidance (although see discussion of the use of the EAC guidelines below), and as such is signposted from the Historic England website stating "The EAC guidance incorporates much of the advice from our 2008 document" (Historic England, 2022). Subsequently archived in 2018, Historic England's website currently states that there is "no firm plan to produce updated guidance", but this update remains a task which Historic England's Geophysics Team intend to complete. Methodology may have significantly developed in the 14 years since the original publication; however, much of the guidance is still considered best practice. Whilst this is a technical document for the most part, it covers the project lifecycle so may also support non-practitioners in planning, commissioning, and reviewing archaeo-geophysical products.

Historic England is England's arms-length government body, and the Geophysics Team continues to offer geophysical survey both for stand-alone projects and in collaboration with the other investigative departments, such as the Archaeological Excavation Team, to help better understand and protect the historic environment. They also support Historic England's Science Advisors with the more complex geophysical queries from LPAs etc. Archaeological prospection communities in England are connected through Historic England's Geophysics Team, who actively support and are supported by the International Society for Archaeological Prospection (ISAP), The special interest group for geophysics within CIfA (the GeoSIG), the journal Archaeological Prospection and the Near Surface Geophysics Group (NSGG) within the Geological Society of London.

The EAC Guidelines for the Use of Geophysics in Archaeology: Questions to Ask and Points to Consider, EAC Guidelines 2 (Schmidt et al., 2015) is the overarching guidance throughout Europe. The document largely brings together Revealing the Buried Past (Gaffney & Gater, 2003) and Historic England's (now archived) guidance (David et al., 2008). A concern with the European guidance is that it is designed to be used alongside national professional standards and legal requirements (Schmidt et al., 2015), therefore country-specific information has been actively removed when transferring the base texts. However, there are currently no active national government guidelines for England. Whilst cart-based systems are addressed in both the English Heritage and EAC guidance, these may benefit from being revisited to continue to steer the sector through challenges that have been encountered as the technique has evolved, such as demonstrating resolution compliance through track plot provision, maximum interpolation and the inclusion of crosslines.

Within the EAC guidelines section "Competence of Survey Personnel" it recommends that a geophysical project manager should have "formal geophysical training" and "extended experience in all aspects of geophysical investigation". This is designed to fit with Historic England's Management of Research Projects in the Historic Environment: The MoRPHE Project Managers' Guide (MoRPHE), which complements the Prince2 project management method (Lee, 2006). MoRPHE guidelines recommend a project manager enlists a variety of "Experts" or "Expert Team Leaders" within specific project stages which, in addition to geophysical survey, may include desk-based assessment, evaluation, excavation, geoarchaeological investigation, post-excavation analysis etc. within a multidisciplinary project.

1.4 Employment

Commercial Archaeology directly contributes £218 m to the UK's economy (2019, Rocks-Macqueen & Lewis). The most recent profile of the profession in the UK does not separate England from the rest of the U.K., nor does it differentiate between intrusive and non-intrusive field staff so there are no definitive figures for the number of archaeological geophysicists in England. To understand the size of commercial archaeology in the U.K., it is estimated that there are 6300 (Full Time Equivalent) archaeologists working in the sector, meaning the sector employs more people than 291 other professions in the U.K. (Aitchison et al., 2021). Despite these figures, the profession is on the official skill shortage list (Home Office, 2022).

CIfA ROs, when filtered for in-house geophysical survey provision and with offices in England, returned 24 results. Of these, two ROs offer marine services and a further three ROs do not include geophysical survey as an in-house service on their website. Of the remaining 19 ROs that offer geophysical survey, some do not appear to have a dedicated geophysics department (or in some cases, dedicated archaeological geophysicists) whilst four of these ROs' primary focus is geophysical provision (CIfA, 2021). However, there are some additional unregistered organisations that also provide geophysical survey services to the archaeological sector.

From data retrieved from the British Archaeological Jobs Resource (BAJR), 116 adverts have been placed for roles in England within archaeological geophysics over the past 5 years by 14 different organisations (Connolly, 2022). The level of knowledge and experience varied from Trainee through to Department lead, with annual salaries ranging from £16.5–42k over this period. This data does not provide exact figures for the number of roles that have been available, as some adverts are for unspecified multiple vacancies, nor is it possible to understand staff turnover within the discipline.

Anecdotally, staff turnover is thought to be reasonably high within the archaeo-geophysical sector in England. Opportunities for progression can be variable, not only linked to unit ethos and policies, but also to financial turnover and business need. Some surveyors may be continuously collecting magnetometer data, which is the main source of income for most units. However, ensuring that surveyors have an understanding of (at a minimum) of all the processes entailed in creating a reliable and high-quality geophysical product is vital in ensuring improved data collection as well as increasing job satisfaction. This is in addition to the difficulties faced in England relating to salary expectations for qualified and experienced archaeological geophysicists. The potentially detrimental effect which working away can have on an individual's personal life and mental health is an issue throughout the wider commercial archaeological sector (de Liaño, 2015). Some units have begun to understand these challenges and guarantee a working rotation to ensure regular office/home-based project work.

1.5 Networks

CIfA's Geophysics Special Interest Group (GeoSIG) is open to CIfA members and Affiliates who have an interest in the sector, with a committee of volunteers who represent the interest of archaeological geophysicists within CIfA. GeoSIG aims to promote the value of geophysics to the archaeological sector and acts as a reference point for other CIfA members (and the organisation) for specialised knowledge and information. It was formed in 2007 to give a voice within the structures of CIfA to U.K. practitioners of archaeological prospection. Early tasks for the group included the specialist matrix for CIfA competencies, as it was very difficult to qualify as an archaeological geophysicist under the previous competencies which were weighted in favour of excavation. The inaugural meeting was held at the University of Birmingham and was well attended with representatives from both commercial and academic backgrounds.

The Geological Society of London hosts the Near Surface Geophysics Group (NSGG) which is a special interest group for disciplines such as Engineering and Mineral Exploration but most pertinently to this review, Archaeology. The group holds a biennial meeting at Burlington House, the home of the Society, in the alternate year to the (also biennial) International Conference for Archaeological Prospection (ICAP). The first in the series was convened by Jenny Allsop of the BGS at Keyworth in 1992, inspired by her experience undertaking geophysical surveys with the Melton Mowbray Archaeological Society. This origin keenly demonstrates the strong links archaeological geophysics has to community archaeology. In the year in which ICAP is convened, the NSGG holds a Field Exhibition at their test site at the University of Leicester. The close collaboration within the community is reflected by the International Society for Archaeological Prospection (ISAP) holding its Annual General Meeting (AGM) at the NSGG meeting. The NSGG often facilitates further cross-discipline collaboration by holding joint meetings where geophysics for both forensic and archaeological sectors is explored.

The International Conference on Archaeological Prospection (ICAP) held its first conference in Bradford, England in 1995, and since then it has also been hosted in Japan, Germany, Austria, Poland, Italy, Slovakia, Turkey, Ireland and France (International Society for Archaeological Prospection, 2022). Similar international conferences have originated in England. The Maxbleep Symposium was first hosted by the Oxford Research Laboratory for Archaeology in 1964. By 1968, this had developed into the Symposium on Archaeometry and Archaeological Prospection following European interest and by 1975 had become the International Symposium on Archaeometry and Archaeological Prospection (Clark, 1996). The International Society for Archaeological Prospection (ISAP) was formally established in 2003, to complement the Archaeological Prospection journal and host the ICAP conference committee. Whilst this is an international group, ISAP was formulated by Armin Schmidt when at the University of Bradford, who with his then colleague, Chris Gaffney, has continued to influence the direction of ISAP.

1.6 Education

In 1973, Arnold Aspinall first offered the foundational course "Master of Arts in Scientific Methods of Archaeology" at the University of Bradford, with the first undergraduate degree course in Archaeological Sciences established the following year. These courses led to the formation of the School of Archaeological Sciences, within the Department of Physics, under the leadership of Aspinall (Schmidt, 2001; Clark, 1996). This was a huge development for the sector, and Bradford remains a centre of innovation for archaeological sciences today. Many of the UK's active archaeological geophysicists have passed through the University of Bradford, which offered the only dedicated Master of Science in Archaeological Prospection course in England. Whilst this course is no longer active, Bradford continues to help educate the next generation of archaeological geophysicists through their current master's level course Landscape Archaeology and Digital Heritage (University of Bradford, 2022).

With the EAC guidelines suggesting formal geophysical training, there is wider sectoral concern that there are no dedicated Archaeological Prospection courses currently available in England. Many universities teach geophysical survey within modules, but a review of currently available undergraduate archaeology courses suggests only a handful of them offer stand-alone modules devoted to understanding both the theory and practice of archaeological geophysics, for example, Bournemouth University offers Applied Geophysics to their undergraduate students and many other universities have archaeological geophysicists on their staff. There are undergraduate and masters courses which teach near-surface geophysics such as at Keele and Liverpool, with the University of Leicester offering an "Archaeological Geophysics Field Course" as an option within their Environmental Science BSc (NSGG 2019; University of Leicester, 2022).

A threat to the profession as a whole is the current vulnerability of academic archaeological departments. Whilst England claims the top three world university rankings for Archaeology undergraduate courses (Quacquarelli Symonds, 2022), "Archaeology in the UK faces a crisis in both professional and academic practice" (Belford, 2021). A number of university archaeology departments in England are threatened with closure, or in the process of being dissolved. This process is reducing the potential number of graduates entering the profession whilst it remains on the official skill shortage list (Home Office, 2022). The industry is campaigning against these decisions, with the Dig for Archaeology campaign and regular lobbying by CIfA (Dig for Archaeology, 2022; CIfA, 2021).

1.7 Community

Whilst the majority of geophysical survey in England is undertaken for commercial purposes, there is a hugely active community (or volunteer) archaeology sector in the UK which often maximises the benefit of geophysical survey on their projects. These projects are important as they investigate the archaeological record where there is no threat or where there is no funding for research. These archaeological geophysicists can be self-taught or receive training and / or support from professional archaeological geophysicists. Whilst the community network is extensive, BAJR maintains a directory of active societies (BAJR, 2022). The following examples demonstrate how community groups might be structured.

Leicestershire Fieldworkers is a network of archaeological community groups, who were able to supply a grant to the Hallaton Field Work Group, one of their member groups, to purchase geophysical processing software (www.leicsfieldworkers.org). With a lead for geophysical surveys on their committee and with geophysical instruments available from within the network, recent training provided by SENSYS and a number of committed and skilled volunteers, they regularly undertake geophysical surveys throughout Leicestershire.

The Local Community Archaeological Training and Equipment (LoCATE) Project is a partnership between Bournemouth University and the New Forest National Park Authority (Welham et al., 2018). The project aims to support local archaeology community groups to increase the skills and techniques available to them by providing instruction and equipment to undertake investigations. The project supported a geophysical survey to locate kilns at Sloden Inclosure, New Forest, undertaken in 2019 utilised the partnership through volunteers led by a university student. The survey followed intrusive investigations in the 1860s, 1915–1927, 1960s and 1989–1990 with magnetometer survey being undertaken in 1993 (Brown et al., 2019).

2 Development

2.1 Origins

The first archaeological geophysical survey in England (and until 2000 thought to be the first worldwide (Bevan, 2001)) is widely accepted as the earth resistance survey undertaken in 1946 at Dorchester-on-Thames, Oxfordshire (Atkinson, 1953). Evershed and Vignoles, at the invitation of Richard Atkinson, undertook the survey, with Atkinson then re-surveying the site himself (Clark, 1996). Atkinson, known for his work on Neolithic and Bronze Age sites (Darvill, 2003), had read about the method and realised the potential for geophysical survey within archaeological investigation (Clark, 1996). Following excavation in 1949, the Dorchester site was interpreted as a multi-phase Neolithic ring ditch and pit circle within a henge monument, the "Big Rings" (Whittle et al., 1992). Atkinson first published Field Archaeology in the same year, his practical, pocket-friendly and "shrewd" fieldwork manual (Hawkes, 1947) in which he wrote in a post-script of his intentions to experiment with archaeological geophysics (Clark, 1996). When the second edition was published, Atkinson included a chapter "The Detection of Buried Structures" (Atkinson, 1953), describing the method in such a way that it might be replicated by other archaeologists.

The instrument used by Atkinson, the Megger Earth Tester, generated the current by the manual rotation of a handle (Atkinson, 1953), but the method used in civil engineering for soil studies was considered too slow for archaeological prospection. Atkinson therefore improved the speed of survey by creating the "leapfrog" method and designed an accompanying switching system (Clark, 1996). The Megger continued to be used as the only geophysical instrument in archaeology until Martin and Clark developed a resistivity meter in 1956 specifically for archaeological purposes, a two electrode, transistorised Wheatstone bridge (Clark, 1996), which was first tested at the Roman town of *Cunetio*, Wiltshire, where it detected the foundations of the defensive town wall (Clark, 1957). The successful trial led to further development of the Martin-Clark Resistivity Meter to improve the effectiveness within archaeology (Clark, 1996). The impact of this invention earned the prototype its place in London's Science Museum (Bartlett, 1997).

The first use of a magnetometer in England followed a lecture at the Society of Antiquities by Canadian physicist John Belshé in 1957. Belshé presented his work dating pottery kilns by sampling their thermoremanent magnetisation. From this lecture, Graham Webster realised the potential for identifying buried kilns in the field, specifically in relation to his current project, The A1 Great North Road. Webster had evidence for the potential for such features along a 3 km stretch of road construction passing *Durobrivae*, a Roman town near Peterborough. Webster, in discussion with the University of Birmingham, and the Research Laboratory for Archaeology and the History of Art, Oxford, led Aitken and Hall to develop a prototype proton magnetometer. The survey covered 5 ha over 7 days, and successfully identified a kiln. It was here they discovered that negative, cut and filled features such as pits and ditches were also identifiable in the data (Clark, 1996). Interestingly, Aitken notes his initial "disappointment" at detecting rubbish-filled pits (Aitken, 1986), but Fowler recognised the benefits of identifying more subtly magnetised induced anomalies to understand the archaeological record, publishing in Archaeometry and refocusing the development of the discipline (Fowler, 1959; Gaffney, 2008).

The first full time archaeological geophysicist in England was Clark, one of the inventors of the Martin-Clark resistivity meter, employed in 1967 when the Ancient Monuments Laboratory (AML) was established as part of the Inspectorate of Ancient Monuments of the Ministry of Public Building and Works (Clark, 1996; Bartlett, 1997). In 1968, Clark took the opportunity to investigate the effectiveness of other emerging geophysical techniques over ditches relating to the Late Iron Age square barrows at Burton Fleming, East Yorkshire (Clark, 1996), later excavated in 1972 (Stead, 1991). A suite of geophysical survey was trialled for comparison, including AML's proton magnetometer and resistivity surveys, the former unsuccessful due to the unexpected presence of igneous material within the underlying geology (Clark, 1996). The new techniques invited to participate were the SCM soil conductivity meter (as a result of this investigation understood to be measuring the soil magnetic susceptibility instead), two versions of the pulsed induction meter (PIM) and an infra-red detector. None of these methods were successful in identifying the ditches, but here began the constantly evolving development of our understanding of the potential and limitations of different geophysical techniques (Clark, 1996).

2.2 50 Years of Archaeo-Geophysics in England

It is widely accepted that archaeological geophysics as recognised today had been developed by 1972, with Clark and Haddon-Reece publishing a paper in Prospezioni Archeologiche on their design for an automatic recording system based on fluxgate gradiometers which would set the standard for industry systems (Clark & Haddon-Reece, 1973; Clark, 1996). By this point, the first fluxgate gradiometer and the direct-reading earth resistance meter had been developed and were being utilised for archaeological prospection. Ground penetrating radar (GPR) and seismic techniques had begun to be experimented with in Japan and the U.S.A. but were yet to be applied to archaeology in England (Aspinall & Haigh, 1999).

Digital logging systems began to be fitted to existing equipment increasing the efficiency of survey. The early Bradphys resistance meter, the predecessor of the Geoscan RM4, was interfaced through an eight-channel analogue-to-digital converter to a portable computer (Kelly & Haigh, 1984), making it capable of storing 1000 readings (Clark, 1996). The Geoscan FM18 fluxgate gradiometer could store 3000 readings on its integral logger (Clark, 1996). By the time Aspinall and Haigh presented their review 'Twenty Five Years of Archaeological Prospection' in 1997 at the Computer Applications and Quantitative Methods in Archaeology (CAA) conference, the capabilities had progressed to the Geoscan RM15 storing 30,000 readings, whilst the FM36 magnetometer 16,000 due to developments in microelectronics and mass storage (Aspinall & Haigh, 1999).

Aspinall and Haigh saw three distinct phases of data processing and interpretation: visualisation, enhancement and reconstruction. In the 1970s archaeological geophysicists were simply attempting to give a visible form to their data, mostly through dot-density plots and contour diagrams (Aspinall & Haigh, 1999). By the end of the 1970s, it was widely assumed that archaeological prospection plateaued as many challenges had already been solved (Gaffney, 2008). In the 1980s, archaeological geophysicists began to improve the visual quality of the data thanks to the cost of computer processors decreasing, with spatial filtering (such as high-pass, low-pass, sharpening and smoothing) and interpolation becoming popular and 3D surfaces beginning to be produced (Aspinall & Haigh, 1999). The focus therefore moved onto advancing inverse data methods to better model potential archaeological features. Aspinall and Haigh also highlighted edge detection as a first step towards auto-interpretation (Aspinall & Haigh, 1999).

By the 1990s, the prevalent method was magnetometry, but all the techniques practised today were available. Whilst instruments were still handheld and expected to cover 1–2 ha per day, a previously unprecedented number of surveys were now being undertaken in England (Gaffney, 2008). The Archaeological Investigations Project undertaken by Bournemouth University for English Heritage recorded the distribution and scale of work from 1990 to 2010 with more than 2700 logged surveys (Darvill et al., 2019). The Geophysical Survey Database, originally created by English Heritage, recorded a further 3247 surveys in the subsequent decade (archaeologydataservice.ac.uk), suggesting an acceleration in the use of geophysics. This investigation is the most accurate understanding of the uptake of geophysical survey in England to date. Since about 2000, the scale of surveys has increased enormously because of long duration projects, new equipment and methods. This growth was intensified by Nationally Significant Infrastructure Projects (NSIPs) using large-scale geophysical survey as a mitigation tool to support energy, transport, and waste schemes.

It was during this period that the Institute of Field Archeologists (now CIfA) published Technical Paper No. 9 *The Use of Geophysical Techniques in Archaeological Evaluations* (Gaffney et al., 1991), which was the first guidance for the sector. The paper was aimed at archaeologists writing briefs or commissioning a geophysical survey and therefore presented geophysical techniques alongside their limitations and suitability for research questions and site conditions. This was superseded in 2002 by Technical Paper No. 6 by the authors, which addressed similar questions but with the benefit of over a decade of sector progression (Gaffney et al., 2002).

In 2001, the Evaluation of Archaeological Decision-Making Processes and Sampling Strategies (Hey & Lacey, 2001), which still today underpins best practice for sampling strategy for archaeological evaluation (trial trenching), was commissioned by Kent County Council. This study included an appendix on “the specific contribution of geophysical survey”, potentially limited by the bias towards magnetic datasets, sample size and data consistency (particularly spatial). From this study, it was considered that 70% of identified anomalies correlated with the subsequently excavated features, with 50% correlated to within 0.5 m. However, the “blank” areas, where there were no significant anomalies identified within the geophysical data were hugely variable (35–87%) (Linford and David, 2001). This reinforced the current convention that absence of evidence within geophysical data alone does not, necessarily, equate with evidence of absence.

3 Current Applications

3.1 Introduction

Archaeological geophysical surveys for commercial projects in England currently should conform to two sets of guidelines: the CIfA Standard and Guidance for Archaeological Geophysical Survey (2014a), and the EAC Guidelines for the Use of Geophysics in Archaeology: Questions to Ask and Points to Consider (2015).

The CIfA guidance defines good practice for the execution and reporting of geophysical surveys, in line with their other guidance and code of conduct. CIfA sets out standards for survey design, briefs, fieldwork, reporting, monitoring, and archiving but does not prescribe appropriate methodologies. The EAC guidelines offer more technical detail on considerations to be made when selecting geophysical techniques and methodologies. The EAC guidelines state that the purpose of a survey should be established at the outset so that appropriate geophysical techniques and survey methodologies can be chosen. They use the categorisation from Gaffney and Gater (2003) to help distinguish three broad levels of investigation:

Level 1—Prospection: to identify areas of archaeological potential and individual strong anomalies
Level 2—Delineation: to delimit and map archaeological sites and features
Level 3—Characterisation: to analyse in detail the shape of individual anomalies

Once the research aim, or purpose, of the survey is established, the most appropriate survey strategy can be determined. Various factors including the known archaeological background of the site, terrain, ground cover, soils, and underlying geology should be considered. The guidelines set out various techniques with suggested configurations and spatial resolutions to help tailor the investigation to the purpose and site conditions.

This section will look at the most widely used techniques within the commercial archaeological geophysical sector in England and how they have changed in use with client requirements and technological advancements. Whilst many surveys now are utilising multi-technique survey strategies, they are better integrated into wider archaeological investigations which may include components such as geoarchaeological investigation or excavation. Interdisciplinary projects are also becoming more common, where archaeological geophysicists may work with external specialists, such as unexploded ordnance geophysicists, to undertake fieldwork or even produce combined deliverables.

Comment on specific manufacturers and instruments is not provided within this review to avoid any potential conflict of interest.

3.2 Magnetometry

The most commonly employed geophysical survey technique in England is fluxgate gradiometry. This is due to the ability to cover large areas for relatively low cost and identify a wide range of archaeological features. Technological advancements over the past 20 years have seen gradiometer survey go from handheld single sensor systems with manual sensor balancing to multi-sensor towed arrays with automatic balancing. These advancements have seen a change in how gradiometer survey is employed in England.

With instruments such as the dual sensor systems (eg Bartington Grad 601-2), an individual acquiring data over individual grids systems may be expected to collect around 2 ha per day. Factors that may affect speed of acquisition include but are not limited to site conditions, sensors, length of working day and experience of the surveyor. These systems were beginning to become essential for large schemes such as HS2 by 2016, and have largely been replaced with cart systems by larger units and those with a geophysical business focus where, depending on site specific factors, such as the uninterrupted size of the field, length of working day and environmental conditions, a vehicle towed array may collect around 20 ha per day in favourable conditions.

The introduction of multi sensor arrays with their associated increase in speed and reduction in cost has seen a real change in how geophysics is deployed in the commercial sector in England. A decade ago, sites in the region of 25–50 ha would have been considered as relatively large, but now sites over 100 ha are commonplace and considerably more affordable. This has changed the perception of archaeological geophysical investigation as a small-scale evaluation solution to enabling a more landscape-scale view of the archaeology.

The cart-based systems are designed to utilise GNSS instruments to give accurate positioning for each data point and are often deployed with four or more sensors at a maximum of 1 m separation. The removal of the need to stakeout individual grids and the increase in deployed sensors both reduces a) cost as less staff are required b) time to cover the same or larger areas. The collection speed has been increased further with the introduction of vehicle towed systems, allowing expected coverage of over 15 ha per day. Contracts for archaeological geophysical survey are regularly won by the overall cost and the speed in which the data can be provided to the client, necessitating innovation.

While technological advances have significantly increased the speed of acquisition, there are factors within the collection of gradiometer data that have not been subject to improvement. The majority of datasets acquired for commercial use are still collected at 1 m traverse separations, as conventional for single and dual sensor systems where there are no requirements for higher resolution, for example as previously mentioned in Norfolk (Robertson et al., 2018). Of note, is the speed in which data can be provided to clients, with some commercial companies providing greyscales within 24 hours, or even providing access to real-time coverage.

There is continued debate over the most appropriate cross-line sensor separation for magnetic survey and whether a 0.5 m separation would offer advantages over the more standard 1 m separation, maximums suggested within available guidance for a Level 1 investigation. The CIfA Standard (2014a) states 'If the project has failed to determine the nature of the detectable archaeological resource within a specified area using appropriate methods and practices because of the way in which it was conducted, the Standard has not been met'. This requirement is most regularly compared to the EAC guidelines' description for a Level 2 survey "to delimit and map archaeological sites and features". As opposed to Level 1, where only "areas of archaeological potential and individual strong anomalies" are expected to be identified. The Standard is likely best reflected by Level 3—Characterisation which requires the investigation to "analyse in detail the shape of individual anomalies" thereby determining "the nature of the detectable archaeological resource". Hey and Lacey (2001) suggest using a sample interval smaller than the dimensions of the smallest feature that can be detected to avoid aliasing.

The EAC guidelines become open to interpretation at Level 2 as, whilst the guidance states a resolution of 0.5 m × 0.25 m or 0.25 m × 0.25 m, it also states that the lower resolution of 1 m × 0.25 m is appropriate for "some" Level 2 investigations. The ambiguity in the level of survey required for archaeological geophysical investigations reflects the disconnect between the guidelines and what is practised in commercial archaeological geophysics in England. The majority of surveys conducted are at a resolution of 1 m × 0.25 m, with perhaps the latter reading interval being smaller. There are only a few counties which specifically request a resolution of 0.5 m × 0.25 m and this is generally only in areas where pit features or a high density of archaeological remains are expected. Until this apparent disparity between the guidelines and practice is clarified, it is unlikely that survey resolution can be driven forward either through universal county archaeologists' requirements or clarification of the factors which define the sensor separation at Level 2.

When reviewing these Standards and Guidelines, it is essential to consider the purpose, or research aim, of a commercial geophysical survey. In general, commercial surveys are commissioned to inform planning decisions or to inform the scope and nature of any further archaeological work in the form of a mitigation or management strategy. This raises the valid question as to whether there is any value in increasing the data resolution for commercial surveys, particularly now that such large areas are being surveyed. Does the detection of smaller pit features and more detail to anomalies add any real value to a survey that is already capable of identifying the larger and stronger archaeological anomalies, when such detection will lead to intrusive interventions?

Conversely, does the real value of increased resolution lie in the potential to identify heavily ploughed down or ephemeral features that may be of archaeological importance and missed by lower resolution survey, and not detectable through intrusive intervention? Should we be developing more “stable” acquisition methods or investigating methods to increasing sensitivity? These questions may be better answered through future reviews of currently available guidance which will better reflect the current state of magnetometry and evolving commercial research questions and requirements.

3.3 Ground Penetrating Radar

GPR is often used either as a complementary survey technique to fluxgate gradiometry or in areas where gradiometry would be ineffective, such as in modern built environments. GPR survey represents a slower and more expensive option than fluxgate gradiometry and, as such commercially, is generally employed over smaller areas. However, as with gradiometry, advances in technology have allowed for vehicle towed multi-channel systems to significantly increase the area that can be surveyed in a day and present GPR as a realistic option on more sites, where the geology, soils and site conditions are suitable for this technique.

The advances in GPR technology follow a similar route to gradiometry within the commercial sector. There is an advancement from single channel GPR systems to multi-channel systems, and eventually to vehicle towing of the multi-channel systems. However, there is a key difference in how these advances have changed the use of this technique. Whilst the development of gradiometer survey has focussed primarily on increasing acquisition speed, GPR has managed to combine this with significant improvements to the resolution of the dataset. Whilst a reduction in cost is mostly realised on larger scale projects where vehicle towed systems can be deployed, the technological advances for GPR survey add significant value to the end product.

The major benefit of GPR survey is that it produces a three-dimensional dataset with responses that allow some degree of interpretation of the archaeological material and state of preservation. While there is a clear advantage to being able to tell the depth of features ahead, or indeed instead, of excavation, the benefits are important when considering the three EAC levels of investigation. The ability to give accurate measurements of features as well as comment on their composition means GPR survey with appropriate resolution is a characterisation survey (Level 3). This makes it a useful tool to target anomalies identified through prospection and delineation surveys. The targeted approach of smaller areas of GPR survey over larger datasets makes it viable on more sites within the commercial sector. However, the ability to identify different anomalies to magnetic survey mean large area GPR survey is a valuable option.

The features generally targeted by GPR survey are similar to those for which earth resistance survey is employed. Both techniques are capable of detecting stone and structural remains that may not be identifiable or as well defined through magnetometry. Over the last 10 years, there has been a combination of the discussed hardware advances in GPR technology, but also advances in the ease and speed of the data processing and visualisation. These advances have brought the cost of GPR survey much closer to that of earth resistance. Given the added value of a three-dimensional data set and characterisation survey offered by GPR, this has seen GPR increasingly replace earth resistance as the second most widely used technique in commercial archaeological survey since the mid-2010s. Whilst earth resistance remains a useful technique, its traditional role is being increasingly reduced as GPR becomes more cost effective and provides much more detailed datasets and interpretation. However, it is important to establish that the site conditions (including, but not limited to, soils and geologies) are appropriate for GPR survey.

The academic community has been actively promoting the use of GPR for research purposes for longer than it has been commonly used within the commercial sector. One of the most well-known examples of largescale GPR survey was undertaken at the Stonehenge and Avebury UNESCO World Heritage Site, in the south-west of England. The Stonehenge Hidden Landscapes Project was undertaken by an international consortium comprising of the Ludwig Boltzmann Institute ArchPro, University of Bradford, University of Birmingham, University of St Andrews, University of Nottingham (Ningbo, China), University of Lampeter and University of Ghent (ORBit). The geophysical surveys utilised seven primary survey methods, including magnetometer, earth resistance, electromagnetic induction (EMI) and GPR. The area covered was 10 km^2 of contiguous mapped area with nearly 170 ha of GPR data collected using both multi-channel arrays and single channel systems (Gaffney et al., 2018). This is the largest project of its kind to date, owing to the range of techniques as well as the site area. The project was widely reported in the media as previously unknown features of significance were identified. A circuit of pits was discovered, which were cored with the resultant artefacts radiocarbon dated to the late Neolithic (Gaffney et al., 2020).

3.4 Earth Resistance

Earth resistance survey was the first geophysical technique to be used for archaeological purposes in England and was once relatively widely used within commercial geophysics, but the efficiencies made in magnetometry and the advances in GPR technology have seen it become less popular.

EAC guidelines state that twin-probe or square / trapezoidal array electrode configurations are preferred for area survey. In England, the majority of earth resistance survey has traditionally been conducted using twin-probe arrays. Advancements in this technology have been relatively limited over recent years when compared to fluxgate gradiometers and GPR, perhaps in part due to the growth of these other techniques. Advances have been made to make data collection more efficient through the use of multiplexers but twin electrode arrays are limited by the practical size and the maximum width of the frame that can manipulated. Multiplexed arrays may improve survey speed and survey spatial resolution but also allow for multiple depths of the sub surface to be targeted, whilst not comparable to the detail provided by GPR these differing depths can greater enhance our understanding. The biggest change in technology has been the introduction of square array carts. These offer collection rates similar to or higher than a single channel GPR survey of comparable traverse separation. However, uptake of this technology has been limited within the commercial sector when compared to other countries, with continuing preference for the detailed three-dimensional data offered by GPR survey in most cases.

The area that earth resistance does maintain its advantage over GPR survey in the commercial sector is its cost. The equipment is cheaper, but more importantly it requires significantly less time to process and interpret the data. This combined with the advances in data collection speed have made earth resistance survey more commercially viable. However, as GPR technology advances with towed arrays it is likely the number of sites where earth resistance is considered the best option continues to reduce. Areas that are too undulating, are too small for a towed array or have adverse surface vegetation which prevent the use of GPR may still be investigated by earth resistance survey.

There is, however, one area of archaeological practice in which earth resistance survey is still widely used. The relatively low price of equipment and software (free of charge, open-source options are available) combined with the ease of use and maintenance make earth resistance survey popular with community groups. Whist this section focuses on commercial geophysical survey due to the significant level of coverage in England, community engagement should be a part of any commercial unit's work and such work adds to the archaeological record in places that commercial funding does not reach. Community groups tend to focus on relatively small survey areas comparative to commercial units but do not have the same time and budget constraints. Both research and commercial organisations working together with local groups add real value and understanding of an area's archaeology and heritage, helping communities to engage with and care for their local heritage assets.

3.5 Electrical Resistivity Tomography

Electrical resistivity tomography (ERT) is not a commonly used technique within archaeological practice in England but offers a good solution to several problems that are not easily solved by other techniques. Within English archaeological investigations, ERT survey is generally conducted as a series of individual lines at relatively wide spacings to produce two-dimensional data rather than employing a close spacing to create a three-dimensional dataset. This is due to it mostly being employed to locate or "chase" known features at depth, such as tunnels, or to provide deposit information associated with palaeoenvironments, and the comparatively high labour intensity of survey when compared to other techniques.

ERT is usually deployed alongside other techniques in order to provide more clarity or detail to the information that has already been gathered. For instance, in the case of a tunnel, it may be that a DBA or trial excavations have located its approximate location and ERT is then employed to provide a more accurate route and depths. For palaeoenvironments, ERT would usually be deployed alongside an array of boreholes or targeted over areas identified by previous survey (Bates & Bates, 2016). The aim would generally be to identify former high points in the landscape that may have formed islands and therefore more likely to contain archaeological material, or former water courses that could support human activity. By combining the ERT data with borehole data it is possible to construct a better-informed deposit model for a site than either technique could separately.

Due to the relatively slow nature of ERT survey it is not a cost-effective technique for a lot of sites. However, with its ability to provide data to depths deeper than most of the other techniques discussed here it can often be the only practical solution. When used as part of a carefully considered and designed survey, alongside other appropriate datasets, ERT can offer information that is not possible through other approaches.

3.6 Electromagnetic Induction

EMI survey provides two complementary datasets in the form of electrical conductivity and magnetic susceptibility. The multiple coil separations of some systems allows data to be collected over different depth volumes. The ability to provide data to depths of ~6 m or more with some instruments makes EMI an effective prospection tool, particularly when looking for large features at depths (e.g. palaeochannels). The nature of the large features being investigated allow for relatively low sampling density and rapid coverage over large areas. This can make EMI a useful technique for identifying paleolandscapes, particularly in waterlogged areas where ERT would not be effective.

EMI has been used to successfully provide detailed data plots of archaeological features, but when compared to gradiometer, earth resistance, or GPR data it generally does not provide the same level of clarity. EMI is probably an underutilised technique in England, with preference given to the other three techniques previously mentioned. However, there is certainly potential for EMI to provide complementary data to these techniques, allowing for an enhanced understanding of certain types of features and sites, as demonstrated by the Stonehenge Hidden Landscape Project (Gaffney et al., 2018).

3.7 LiDAR & Remote Sensing

Advances in other areas can also be utilised to enhance interpretation of geophysical data. The National LiDAR Programme undertaken by The Environment Agency aims to provide accurate elevation data at 1 m spatial resolution for the whole of England, with some areas available with spatial resolutions to 0.25 m. This offers an easily accessible resource for identification of archaeological features. Combining LiDAR data with geophysical survey data means it is possible to evaluate both extant and below-ground remains, enhancing the overall interpretation of a site and, in turn, providing a more complete baseline for effectively managing the archaeological risk through mitigation strategies and further investigations.

In addition to LiDAR, other sources of remote sensing data are becoming more commonly used due to the advancements in uncrewed aerial vehicle (UAV) survey and sensors. As UAVs have become capable of carrying larger payloads for longer flight times, it is now possible to offer a wider range of remote sensing services at a more commercially viable price. LiDAR, multispectral, hyperspectral, and photogrammetry data can now all be gathered efficiently using UAV survey, offering more options to be considered alongside geophysical survey at the initial evaluation stage. As well as this, the sensors are improving, allowing for higher quality data and better interpretation. Being able to select and combine appropriate survey techniques for specific sites is starting to greatly increase the information available and aiding management of archaeological risk.

3.8 Archiving

The contentious issue of archiving archaeological geophysical data in England is heavily debated. The standard was set by Schmidt in 2001 with his publication Geophysical Data in Archaeology: A Guide to Good Practice. The majority of invitations to tender will stipulate archiving to this standard along with an OASIS report, and the updated edition published in 2013 is referenced in the EAC guidelines (2015). However, a brief consultation of the Archaeological Data Service (ADS) website is enough to demonstrate that this practice is not universal. During 2021, 13 surveys were uploaded to The Geophysical Survey Database, despite practitioners widely reporting high volumes of available work.

The ADS is the only accredited digital repository for heritage data in England to ensure the long-term digital preservation of data. Whilst the ADS was established with funding (from the Arts and Humanities Research Council & the Joint Information Systems Committee) it is now predominately project funded, and underwritten by the University of York, where it is based. Each deposition has an associated cost, with the costing calculator calculating a quote of £192 for 1 ha of geophysical data and £522 for 50 ha in July 2022. Whilst some planning authorities in England and Wales now request an ADS quote to be submitted as part of a Project

Design, the absence of archiving costs can become the deciding factor. Cost is also a constraint for community groups however, the ADS offer the Open Access Archaeology Fund to support such investigations with the cost of publishing and archiving (www.archaeologydataservice.ac.uk).

OASIS is an online tool to share details of archaeological investigations with Historic Environment Records (HERs) (resources that relate to defined geographical areas, e.g. a county). Some organisations now include as standard their completed but unsubmitted OASIS form to demonstrate their compliance. The records are received then checked by the ADS and, where used by the local HER, checked by the appropriate authority, with the option to submit to other organisations such as Historic England. The records submitted are publicly and freely available through the ADS (www.oasis.ac.uk).

4 Future Focus

4.1 Future Guidance

As planning legislation in England is currently under review, there is no better time to update national guidance. The EAC guidelines are designed to work in tandem with country-specific guidance therefore the forthcoming Historic England update will be hugely beneficial to the sector. The overarching question currently is to what extent should it be procedurally prescriptive as opposed to allowing practitioners flexibility in methodology by simply specifying the outcome that must be achieved. There is also the difficulty in ensuring that any guidance is "future-proof", and to some extent the latter approach would allow for innovation. There is no question however that quality must be a consideration to any future advancements, in addition to improving survey speed and reducing cost. CIfA are currently updating their guidance for geophysical survey and ensuring that non-practitioners are included in the consultation to improve the support provided for users of geophysical products, as well as specialists.

Future reviews of available guidance would benefit from consultation throughout the range of potential stakeholders, from county archaeologists to geophysical units and the archaeological organisations that are end users of the data to help design mitigation strategies and excavations.

4.2 Data Acquisition

Within the commercial sector, future development will continue to be driven by reduction of cost or adding value to the data beyond what currently exists, such as with GPR survey replacing earth resistance for many sites. The easiest way to reduce cost for commercial survey is to reduce either the number of people required or the time that they are needed on-site. This has already been seen with the introduction of vehicle towed arrays which have become common place over the past 5 years.

A comparison of current cart-based fluxgate gradiometer systems with UAV based fluxgate systems show that while the UAV collected data is able to identify many of the same anomalies as cart-based survey, it does not show the same level of detail (Magnitude Surveys, 2021). The comparison does however show that UAV based survey is effective for at least identifying large and strong magnetic anomalies. This suggests that there is some use for Level 1—Prospection survey within areas that are hard to reach or considered too dangerous to physically survey, such as mountainous or intertidal areas. If the resolution can be improved, then UAV survey has the potential to offer many advantages over towed survey. UAV survey has the potential to offer greater collection speeds, be more environmentally friendly than vehicle towed systems, and remove the issue of ground conditions and crop damage. These questions are still very much in the process of being actively studied, researched and evaluated though and have achieved some promising results to date.

While the sensitivity of UAV collected data is currently an issue, a shorter-term goal of automating data collection could be to review the equipment that is currently being used. Until the sensitivity of UAV survey can reach an acceptable level for archaeological use, it is possible that land-based self-steering vehicles could provide a cost-effective enhancement to current towed systems or via improvements to sensor arrays.

4.3 Automation

Automation is likely to be seen increasingly in the processing and interpretation of datasets. Many processing software programs already offer automated or semi-automated options that apply standard processes to datasets. However, these still require overall quality control and adjustments by a geophysicist. With advancements in machine learning and artificial intelligence it is likely that identification of anomalies can, to some degree, be automated to complement user-led interpretation (Killoran, 2021; Kramer, 2022).

However, such developments could potentially lead to reporting becoming more of a compilation task than an archaeological interpretation of the data. It is most likely that artificial intelligence will be used as a tool to significantly increase the speed of digitisation and reporting, allowing for more focused interpretation and quality control to be provided by an experienced archaeological geophysicist.

4.4 Multi-Technique Platforms

One potential way of both reducing cost and increasing value is through the use of multiple techniques simultaneously. While many of the available techniques are not able to function in close proximity to each other, the potential of EMI and gradiometer sensors on a single cart has been proven. This offers a minimum of three datasets collected in the time of a standard gradiometer survey, with the gradiometer data alongside the conductivity and magnetic susceptibility from the EMI. The gradiometer and conductivity data offer complementary datasets similar to that of gradiometer and earth resistance data.

While the value added to the interpretation by including an additional dataset likely outweighs the increased costs from processing time, there is a reduction in safety for surveyors using manual carts. Adding further instruments and sensors to any array will increase the weight and therefore increases the risk of injuries associated with manual handling. It may be possible to mitigate some of this risk through the design of the cart or platform, but the best way is to remove it is through vehicle towed survey. However, not all sites are suitable for towed survey due to access, the risk to crops, surface obstacles or the size of the survey area. In these cases, the increased manual handling risk would need to be properly assessed to determine whether the survey is viable.

4.5 Deliverables

While much of this chapter has looked at developments with techniques and methodologies of survey, it is important to consider the end product of any survey, the report. As much as there has been value added to the data being fed into reports over the last 10–20 years, there has been little advancement in reporting, or how the data and interpretation is managed. Of these advancements however, graphical improvement over the past two decades to how the geophysical data is displayed and presented in reports should be noted. With better availability of more sophisticated CAD packages, graphics software such as Adobe Illustrator/CorelDraw etc and Desktop publishing software with a large range of price points to suit all resources, and even free alternatives which have allowed less well-resourced practitioners proportional improvement, such as community groups.

The increased use of GIS software in all aspects of archaeology also offers potential to add value to the end product of a geophysical survey with the production of an overarching geodatabase. Currently an interpretation drawing, produced in a variety of software, might be shared to aid evaluation at the DBA stage or to help place trenches for evaluation. However, it is unlikely that this drawing holds much information beyond polygons and interpretation categories. GIS software offers the ability to add more information to individual anomalies through the addition of an attribute table per interpretation category that contains several informative fields.

By adding interpretive attributes to anomalies within GIS, it is possible to add considerable value to an interpretation drawing as a standalone product, such as The Landscape Research Centre's work in the Vale of Pickering (www.thelrc.wordpress.com). This is not to say that a full written report would not be required, rather that by adding field values within the attributes for each interpretation category within a GIS it becomes more user friendly for both internal and external users. This can ultimately help to create a more cohesive project where individual elements and data sources can be easily cross-referenced, saving time and creating a more rounded overall product. There is precedent for this way of working; NSIPs, such as HS2, often work with an overarching schema for geodatabases. This helps to ensure a consistent approach to interpretation and display of data throughout the lifecycle of a project with multidisciplinary teams. This may also improve archiving, as the resulting added metadata and more standalone product would be much more "archive-friendly" for preserving geophysical survey derived information for the longer term.

While the advancements in survey technologies allow for more detailed datasets, there is perhaps little that can be done to improve the written interpretation without changing the standards and guidelines of what is considered acceptable interpretation. Increasing automation and processing speeds should allow more time to be focussed on archaeological interpretation of the data, allowing for reports that offer considered insights. Once an anomaly has been identified, archaeological interpretation firstly ascertains whether an anomaly is anthropogenic and/or archaeological, and suggests the feature the anomaly may represent e.g. ditch, gully, pit. Where possible, further information (referring back to the background research available e.g. DBA) as to the period and potential function of the feature e.g. Romano-British ladder enclosure, Bronze Age Banjo enclosure, medieval house platform may then be included, but this relies on the knowledge and experience of the archaeological geophysicist and the known historic environment context.

The quality and extent of archaeological interpretation is highly variable currently. Some units include only whether they consider an anomaly to have the potential to be archaeological, others will identify the potential feature but not all continue through to full archaeological interpretation of the feature within the historical setting. These disparities would benefit from clarification as to the extent of interpretation required for the intervention, whether that be through the research question, project brief or through guidance. However, within a competitive commercial setting, it is more likely that these time savings will be used to provide more competitive costings. The drive for higher standards of reporting would need to come through the standards and guidelines with proper evaluation and enforcement by LPAs rather than individual units and practitioners.

5 Conclusion

England was an early adopter of archaeological geophysics, the experimentation undertaken and the organisation of the sector between the 1940s and 1970s allowed for a recognised and resilient industry to develop. Archaeo-geophysical practices were established from the early 1970s, with the value to the wider archaeological sector becoming understood. There are of course many improvements we continue to make to our processes, but one of the distinguishing features of the use in archaeological geophysics in England is the framework of standards and guidance available, alongside the sheer volume of geophysical data collected by the commercial sector. Indeed, this is demonstrated by how the EAC guidelines adopted the majority of *Geophysical Survey in Archaeological Field Evaluation* (2008) for wider use throughout Europe.

Innovation within archaeological geophysics needs an environment in which it is encouraged, and experimentation is not only permissible but encouraged to sustain development. It is the responsibility of the geophysical sector to ensure that non-practitioners, whether professional or community based, are engaged and educated in the value and limitations of all forms of geophysical survey. We also need mechanisms to share good practice in an open and transparent manner. As demonstrated, England's archaeological geophysical community is hard to detach not only from the U.K., but from the European community. It is through the global collaboration of archaeological geophysicists that we have developed our profession as significantly and rapidly over the past 75 years. The discipline continues to combine efforts to advance archaeological geophysical practice to better understand and protect our heritage.

Acknowledgements The authors would like to thank Neil Linford, Paul Linford and Andy Payne their comments and contributions to the original drafts. They also would like to thank Tim Darvill, Tom Cromwell, Eileen Wilkes, Louise Tizzard, Nicholas Crabb, David Connolly, Michal Pisz, Laurence Shaw, Chris Gaffney and Nicola Hembrey for their kind support.

Lucy Parker is currently a Collaborative Doctoral Student at Bournemouth University working with Historic England on the research project *Geophysical Surveys in England: Using digital data to inform heritage management and promote collaboration*. Her work is supported by the Arts and Humanities Research Council [grant number AH/W002566/1].

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