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Looking to the Future, Caring for the Past

Preventive Archaeology in Theory and Practice

Proceedings of the 2013-2014 Erasmus IP Summer Schools
in Preventive Archaeology:
Evaluating sites and landscapes. Methods and techniques for evaluating the archaeological value

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Table of Contents

CHANGE IS GOOD: ADAPTING STRATEGIES FOR ARCHAEOLOGICAL PROSPECTION IN A RAPIDLY CHANGING TECHNOLOGICAL WORLD

James Bonsall
Chris Gaffney

Introduction

The use of geophysical prospecting has only been part of the commercial archaeologists toolkit for a relatively short time. Although individuals offered small scale surveys (usually earth resistance) in the 1970s and early 80s for 'rescue' or contextualising excavations, it was not until the first magnetometers with digital output and onboard memory (produced by Geoscan Research) were available in the late 80s that the technical ability of the geophysicist was suitable for solving more substantive archaeological type problems. The present commercial position is considerably advanced by comparison to the 70s and 80s and the use of geophysical techniques has expanded to record levels in many countries. The technical changes that are evident in the discipline since the start of this millennium have been profound and have driven change in working methods, speed of data capture and reliability; there are long-term benefits in efficiency and cost. It is true that in some areas the acceptance has been slower but there are often particular reasons for this. Within this article we will consider the use of geophysical techniques for commercial style work in Ireland and the UK. On first glance these two adjacent countries may be expected to have a similar trajectory with respect to geophysical use but closer analysis reveals significant variations.

Within the UK there have been guidelines on how to work in commercial style projects since 1991[1] via the Institute of Field Archaeologists (IFA, now the Chartered Institute for Archaeologists, CIfA). However, more comprehensive statements appeared from English Heritage (EH) in 1995[2] and both CIFA and EH subsequently updated their advice with David *et alii* (2008) now the best and most exhaustive work. Somewhat paradoxically the EH guidelines are now the de-facto guidance for geophysical work in many countries beyond England. The impending publication of pan-European guidelines is also underpinned by David *et alii* (2008) which will allow some certainty across a wide geographical region regarding at least choices prior to data collecting. These guidelines, written under the auspices of the Europae Archaeologiae Consilium Working Party in partnership with the Inter-

1 Gaffney *et alii* 1991.
2 David 1995.

national Society for Archaeological Prospection (ISAP) and the Aerial Archaeology Research Group (AARG), will be valuable for creating national variations in approaches that are suited to differing archaeological or geological conditions.

Within the UK the GeoSIG (Geophysics Special Interest Group) of CIFA has become something of an umbrella group joining both practitioners and local / national government bodies such as EH and planning authorities. While that group has helped to refine some of the David *et alii* (2008) statements, it has also suggested a definition for the term 'archaeo-geophysical'. Their definition is that "archaeo-geophysical survey uses non-intrusive and non-destructive techniques to determine the presence or absence of anomalies likely to be caused by archaeological features, structures or deposits, as far as reasonably possible, within a specified area or site on land, in the inter-tidal zone or underwater. Geophysical survey determines the presence of anomalies of archaeological potential through measurement of one or more physical properties of the subsurface"[3]. While some[4] have suggested that this definition is too narrow for research based geophysics, it is fit for the purpose of describing the use of geophysical techniques in commercially led archaeological projects.

This paper will consider some aspects of the practice of commercially led archaeological geophysics in both the UK and Ireland in the light of the current accepted use of the techniques. It provides an important comparison as the former has a mature, professional and relatively large number of commercial geophysical groups that specialise in archaeological applications while the latter has a emerging commercial setting.

Some comparative data between the UK and Ireland

In order to understand the use of geophysical techniques in the UK and Ireland and the perceived outcomes in each country, it is necessary to compare the factors that shape the use of the most commonly used techniques. While it is important to recognise that Northern Ireland falls under (commonly based) UK legislation and is driven by UK economic practices in terms of construction output and therefore the frequency of development-led archaeology, Northern Ireland shares many of the same environmental, archaeological and socio-economic cultural factors as the Republic of Ireland. When combining the two influences from the UK and Ireland, Northern Irish commercial archaeology is somewhat of an anomaly to their respective neighbours, and does not easily fit in with either of their state-regulated systems.

Geological background

Irish geology is substantially different from that of the UK and is dominated by sedimentary rock across most of the country. Carboniferous limestone is the most widely distributed rock on the island of Ireland[5] and tills (known in the UK as 'boulder clay') comprise the majority of the surface geology[6]. Chalk deposits are limited in Northern Ireland and (with one exception) are entirely absent in the Republic of Ireland[7], but chalk is relatively common in England and many of the most successful magnetometer surveys that are cited in the literature have been undertaken on this geology e.g. Gaffney *et alii* (2012). Metamorphic rocks are found in isolated regions in the SE of Ireland (Counties Wexford, Waterford and Wicklow), Co. Donegal, NW Co. Mayo and NW Co. Galway; Igneous rocks are commonly encountered near areas of metamorphic rocks, principally in N. Ireland (which contains the most frequent igneous deposits), the SE of Ireland (Counties Wic-

[3] CIFA 2014.
[4] Gaffney, Gaffney 2011.
[5] Gillmor 1971.
[6] Bonsall *et alii* 2014.
[7] Limited to the NE coast of N. Ireland and very small isolated pockets at Ballydeenlea, Farranfore, Co. Kerry.

klow, Wexford, Carlow), SW Co. Galway, central Co. Mayo and NW Co. Donegal[8]. Intrusions of igneous dykes are common in Irish sedimentary geology[9] and glacial igneous erratics can be found across the country.

Climate

There are a number of key similarities and differences in the climates of Ireland and England. The climate of both countries are strongly influenced by the North Atlantic; sea-level pressure is responsible for more than 25% of the precipitation variability of Ireland and the UK[10]. The continentality index (assessing climate data and latitude) indicates a relatively high maritime influence on the temperature of Ireland and the UK, which are comparable to those in Iceland, New Zealand and central South America[11]. Despite the dominant influence of the North Atlantic, both Ireland and the UK are afforded a reasonably stable and mild climate, mostly without the extremes of temperature experienced by many other countries at similar latitude e.g. seasonally very cold periods encountered in Canada, the northern US, northern China, Russia and parts of Europe.

The key climate differences are apparent due to the soils of the British Isles[12], which indicate that Ireland is a mostly humid temperate country, contrasting with England – which is a mostly subhumid temperate country – and Scotland – mostly humid (oro) boreal and perhumid (oro) boreal country. Comparative climatic regimes to Ireland are found regionally in the UK, such as Devon and Cornwall (SW England), most of Wales, NE England and around the edge of southern Scotland. These climatic regimes result in a generally wetter climate for Ireland, due to higher precipitation and less evapotranspiration than in the UK, although both countries enjoy broadly similar annual mean temperatures. These, combined with topography, affect the development of surface soils and subsequent land use.

Soils

Podzols are the most widely distributed soils in Ireland (>25%), more than twice the frequency of those in England; these are followed by poorly drained gley soils and peats (mostly in the NW) and free draining brown soils (mostly in the south and east). Less than 10% of Ireland is covered by thin lithomorphic soils which are found extensively on rock-outcrops of karstic Carboniferous limestone. Peat coverage across Ireland (16.5%) is extensive (the third highest in Europe) and is much more frequent than the UK[13].

Land use

Ireland's 'good agricultural land' occupies 50.1% of the country and is largely pastoral, however 28.6% of Irish land is very poor and 21.0% is 'limited' in its range of potential uses (to permanent grassland), mainly because of poor drainage[14]. Commercial developments in Ireland tend to occur upon the 'good' and 'limited' land, although 'very poor' land (including woodland and blanket peats) is often crossed by large-scale infrastructure projects. Artificial surfaces in Ireland account for 2% of the Irish landmass, which is half of the Europe-wide average, leaving 98% of Ireland in a natural or semi-natural (i.e. undeveloped) state.

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8 Bonsall *et alii* 2014.
9 Gibson, Lyle 1993; Gibson *et alii* 2009.
10 Murphy, Washington 2001.
11 Hargy 1997.
12 Avery 1990, p. 24.
13 Avery 1990, p. 400; Montanarella *et alii* 2006.
14 Gardiner, Radford 1980.

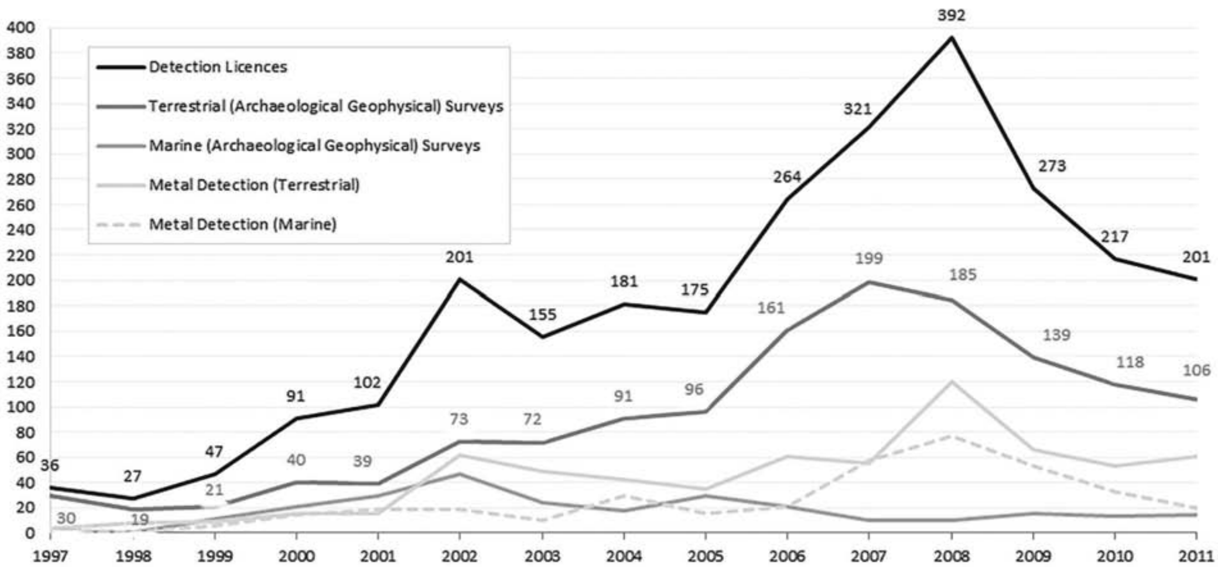

Fig. 1. Detection Device Licences for archaeological geophysical surveys issued by the National Monuments Service in the Republic of Ireland between 1997-2011.

Background to Archaeological Geophysical work in the UK

General textbooks have illustrated the time depth that geophysical techniques have been used in the UK. More particularly there is also literature pertaining to the commercial work undertaken in the UK[15]. It is reasonable to say that archaeological geophysics has enjoyed great *commercial* success throughout the UK, possibly more so than any other country in the world. Despite this statement, accurate estimates for the frequency of commercial survey use of geophysics are rare. Estimates from England (which include both commercial and research surveys) suggest that at least 450 geophysical surveys were occurring annually in 2003[16] and that it was used on at least 23.4% of commercial evaluations arising from planning applications[17]. Reliable updated estimates do not exist primarily due to the lack of any licensing requirement prior to survey. However, some archives / legacy summaries do offer support for the anecdotal increase in geophysics in the last decade.

Three archives can be identified that give indications of survey use in England. The Archaeological Investigations Project (AIP) catalogue of grey literature (both commercial and academic) from England records an average of 266.6 surveys annually between 2001-2010[18]. These figures rely on voluntary submissions and should be regarded as a minimum number rather than an accurate guide to the full scale of prospection surveys. Between 1990 and 2010 it is calculated that the AIP archive identified 2,704 *unique* records of geophysical surveys. The second archive is an independent review of 1,102 surveys in the East Midlands region between 2001-2006; on average 183.6 surveys in this region per annum[19]. Finally, the English Heritage Geophysical Survey Database[20] records 748 surveys between 2001-2010, on average 74.8 per year, which reflects English Heritage's own surveys and those of other practitioners who survey on sites that are protected by legislation. Survey of such sites requires a formal report as part of the agreement from EH; given the protected nature of 'scheduled' sites it is unlikely that a high proportion of surveys in this database are related to commercial style surveys.

[15] See Gaffney 2009.
[16] Gaffney, Gater 2003.
[17] David *et alii* 2008.
[18] AIP 2012.
[19] Knight *et alii* 2007.
[20] English Heritage 2012.

Method	**Active or Passive**	**Frequency of Use in the British Isles**			
		UK	Republic of Ireland (%)		
			Description	*n*	%
Magnetometry	Passive	High	High	1,139	53%
Electrical Resistance	Active	High	High / Mid	653	31%
Magnetic Susceptibility	Active	Mid / Low	Mid	199	9%
Ground Penetrating Radar	Active	High / Mid	Mid / Low	102	5%
Electromagnetic	Active	Mid / Low	Low	23	1%
Metal Detectors	Active	Low	Low	17	<1%
Seismic	Active	Low	Low	3	<1%
Microgravity	Passive	Low	Low	1	<1%
Induced Polarisation	Active	Low	None	0	0%
Self Potential	Passive	Low	None	0	0%
Thermal	Passive	Low	None	0	0%
Total				**2,137**	

Table 1. Archaeological geophysical techniques used in the British Isles, by Bonsall (2014). The UK data were estimated by Gaffney and Gater (2003); the Irish data utilises terrestrial (archaeological geophysical) Detection Licence applications from 1997-2011, assessed by Bonsall (2014). The Licence applications indicate only an aspirational use of technique(s). Nonetheless, it does give broad indications into the frequency of geophysical techniques.

The three archives are drawn from three distinct populations although there must be some degree of overlap between them. Nevertheless, these figures give a reasonable indication of the very frequent use of geophysical survey in England although the number of events gives no clue as to the size of the surveys.

In commercial led surveys in the UK there has been a distinct and verifiable move away from context and rescue toward discovery of new 'sites' and the mapping of their extent. As a result it can be shown that geophysical surveys are integral to the activity of information acquisition that is part of the UK planning process. In that guise the techniques are often used early in the process and sometimes the first to produce new information that relates to lacuna that are evident from desktop searches.

The techniques that have been used in the UK can be seen in Table 1. Those that have been used frequently are the techniques that have a regular place in commercial style work and by some clear margin magnetometry is the most used technique. The reasons for this have been identified elsewhere[21] and primarily relate to speed of data capture, ease of interpretation and the perceived overall positive response to many types of archaeology over many types of geology.

Within the UK commercial environment there has been a radical change in the implementation of the most prevalent technique i.e. magnetometry. Until recently, handheld devices have allowed either dense data collecting or fast area coverage. Commercially the latter has been the focus and has been defended with reference to the concept of presence or absence that appears in the GeoSIG definition of geophysical survey. However, the greater prevalence of cart systems (both human and vehicle propelled) with modular sensor arrays has provided the opportunity for both large scale and dense data capture. A result of this change is finer resolution in commercial maps and this will provide significant value in forthcoming grey literature reports.

Some generalisations can be stated about the use of geophysical techniques in the UK. A commercially-driven survey undertaken to the GeoSIG Standard – and using the latest methods of data

[21] Gaffney 2009.

capture – will, as far as possible, inform on the presence or absence, character, extent and in some cases, apparent relative phasing of buried archaeology. This may allow an assessment of its significance and may lead to one or more of the following:

a. The formulation of a strategy to ensure further recording, preservation or management of the resource.

b. The formulation of a strategy to mitigate any perceived threat to the archaeological resource.

c. The formulation of a proposal for further archaeological investigation within a programme of research. It is usually the case that the geophysical survey is a component of a larger integrated research strategy. Of course, if all elements show little or no potential in an area of interest then the survey still would be reported and lodged with the relevant authority.

Commercially, there are a number of triggers that may induce the need for a geophysical survey. The need is often a result of one of the following:

a. In response to a proposed development which threatens a known or potential archaeological resource

b. As part of the planning process (within the framework of national planning policy guidance notes and/or development plan policy)

c. As part of an Environmental Impact Assessment (EIA)

d. Outside the planning process (e.g. ecclesiastical development, coastal erosion, agriculture, forestry and countryside management, works by public utilities and statutory undertakers)

e. Within a programme of research not generated by a specific threat to the archaeological resource

f. In connection with the preparation of management plans by private, local or national and international bodies.

An archaeological geophysical survey may therefore be instigated or commissioned by a number of different individuals or organisations, including local planning authorities, national advisory bodies, government agencies, private landowners, developers or their agents, archaeological researchers, community groups, etc.

Background to Archaeological Geophysical work in Ireland

Like the UK, Ireland is a signatory State of Article 3.I.b. of the European Convention on the Protection of the Archaeological Heritage (the 'Valletta Convention' of 1992, ratified by Ireland in 1997) which specifically requires members to "ensure that archaeological excavations *and prospecting are undertaken in a scientific manner and provided that non-destructive methods of investigation are applied wherever possible*"[22]. In Ireland, this has resulted in a 'polluter pays' system, that requires the developer to fund all archaeological works (from environmental impact statements through to post-excavation) related to a given development, from single house construction projects, to ancillary farm buildings, residential estates, quarries, commercial and manufacturing works and infrastructure such as roads and pipelines. The legislation is enacted by the National Monuments Service (NMS) on behalf of the Dept. of the Arts, Heritage and the Gaeltacht government ministry.

The Republic of Ireland's population is just over 4.5 million people. The comparative population density of the Republic of Ireland (65/km^2) is half that of Northern Ireland (133/km^2) and much lower than that of the UK (256/km^2). Irish towns and cities are much smaller than those of the UK, and whilst there is a continuing demand for Irish housing and infrastructure, the scale is much lower than that of the UK; the number of planning permissions granted in the Republic of Ireland[23] in 2013

[22] Government of Ireland 1999.

[23] Central Statistics Office http://www.cso.ie/quicktables/GetQuickTables.aspx?FileName=BHA03.asp&TableName=Planning+Permissions+Granted&StatisticalProduct=DB_BB.

Fig. 2. Multi-sensor cart-arrays are gradually increasing in usage across Ireland. Challenging field conditions – such as rough and poorly drained ground – may preclude some of the advantages offered by ATV-powered arrays, whilst pedestrian-powered carts are extremely useful for the collection of high-resolution data.

was 13,901 (all types of construction), of which 3,316 were dwellings, which can be compared with the construction of 122,590 new homes started in England[24] during 2013.

Despite some exceptions[25], Irish archaeological geophysics did not begin to see any notable advances or frequency of use until the 1980s, which differs from the UK and European experience of research, innovation and experimentation[26].

The early geophysical research in Ireland was mostly carried out by researchers at Queens University Belfast, University College Cork, the National Universities of Ireland Galway and Maynooth from as late as the 1980s. These institutions, combined with the work of the government funded Discovery Programme, surveyed mostly high-profile or royal sites, monuments and landscapes[27] – that demonstrated archaeological prospection techniques were useful methods of assessment in Ireland. However, these successes were limited to research work, and it was not until an economic boom in the 1990s that geophysical surveys gradually became more widely adopted.

All archaeological fieldwork is tightly regulated in Ireland and this is a key difference to the position in the UK where only work at legally protected sites are licensed. In 1987 the use of geophysical

[24] UK Government Statistics https://www.gov.uk/government/collections/house-building-statistics.

[25] Aitken 1959; Aitken *et alii* 1958; Byrne 1995; Hartwell 1988; Wailes 1970; Doggart 1983.

[26] Aitken *et alii* 1958; Aitken 1959; Aitken 1961; Dabrowski 1963; Hesse 1962; Lerici 1961; Ralph 1964; Scollar 1964; Colani, Aitken 1966.

[27] Barton, Fenwick 2005; Corcoran 2007; Johnston *et alii* 2009; Newman 1997; Waddell *et alii* 2009.

equipment for archaeological prospection was restricted via a government licensing system to deter the use of metal detectors and illegal excavations. A government 'Consent to use a Detection Device' ('Detection Licence') is required for all geophysical surveys of archaeological features, objects, deposits, wrecks or caves. Similar licenses and ministerial consents are also required under the National Monuments Acts 1930-2004 and the National Cultural Institutions Act 1997 for archaeological excavations, dive surveys, exporting archaeological objects.

The Detection Licences issued by the National Monuments Section (NMS) have ensured that quantitative data are available to chart the use and frequency of geophysical surveys, which includes amongst other information, the types and number of proposed techniques to be used on a given geophysical project. A single Detection Licence can be issued for more than one geographical area e.g. an infrastructure scheme over several km could be covered by one licence. Similarly, one licence can cover a range of geophysical survey techniques, however if an additional technique is required a new licence (or a licence extension) must be applied for.

During the economic boom of the 1990s, both knowledge and personnel were imported into Ireland and a substantial amount of fieldwork was carried out by UK-based consultants due to the lack of local expertise in Ireland. As such, the subsequent use of geophysical techniques and methods in Ireland were strongly modelled on the UK experience. In particular an emphasis on the use of unrecorded magnetometer scanning and topsoil magnetic susceptibility surveys as a preliminary means of reconnaissance was apparent; this was a pragmatic response to increasingly large survey areas which has since been superseded by technical advances.

In practice, archaeological geophysics is not universally applied by the NMS "wherever possible" (as suggested by the Valletta Convention) but is mostly only used in advance of developments that are upon – or near – known sites in the statutory list of Record of Monuments and Places (RMP). It can be noted that large-scale users of commercial archaeological geophysical surveys (e.g. government funded infrastructure projects) sometimes commission such assessments without a pre-planning requirement issued by the NMS. Those are generally the exception and most commercially funded geophysical surveys will occur only as a pre-planning requirement.

Geophysical surveys in Ireland are most frequently commissioned following a desk-based assessment and a walk-over survey, once an archaeological site, or the suspicion of a site, has been identified. Following a geophysical survey, test trenches are excavated, both in a random pattern across a site and to specifically assess significant geophysical anomalies. Archaeological deposits and objects are protected by Irish law. Unlike the UK, archaeological features threatened by development in Ireland must be fully excavated (e.g. features are not sampled) and – in theory therefore – every archaeological object should be recovered and ultimately deposited in the archives of the National Museum of Ireland. Archaeological features identified by test trenches will be resolved via a final phase of fieldwork centred on an open area archaeological excavation.

What role can archaeological geophysics play if a development zone is entirely excavated of all features, without a sampling strategy? Test trenching will occur across development sites where possible[28] and such a method is capable of identifying large enclosures, just as many geophysical techniques potentially can; however test trenches are less likely to identify and work out the significance of small and isolated features. Geophysical surveys can add value and offer substantial benefits over intrusive methods by identifying these small-scale features.

Initial site identification and delimitation is also important, but unlike the UK where geophysics can often be used to 'fill in the blanks' of evaluation excavation, all features will be recorded on an Irish excavation, removing a (seemingly unrequired) benefit offered by geophysical assessments. Instead, geophysical surveys in Ireland are used as a pre-planning requirement to help mitigate developments – the discovery of a significant archaeological site or monument via geophysical assessment

[28] O'Rourke 2003.

can require a conditional redesign of the development (e.g. incorporating such a site into a 'green space' or recreation area, with minimal or no impact) or denial of planning permission outright. A consequence of this is that, in Ireland, survey is often undertaken beyond the expected limits of linear projects – this allows re-alignment of roads and pipelines to avoid archaeological excavation and, hence, reduce costs.

The excavation of a large enclosure ditch can require several months of fieldwork, adding significant costs and potential delays to development projects. In Ireland, geophysical surveys are used as a mitigation tool in advance of excavation, not in spite of. A 100% excavation of archaeological features is labour intensive and requires a substantial amount of planning, whereas a geophysical survey can determine the size and extent of a monument, the type of archaeological features encountered and their depth (dependent on technique used), which are used to calculate how much time a full resolution excavation may require. In Ireland, geophysical survey is increasingly being used to identify such development 'hazards' at any early stage, allowing planning departments and developers to mitigate for such outcomes.

The archive of Detection Device Licences allow us to examine in detail which methods have been used in Ireland. The licences are aspirational and may be issued for multiple techniques when in reality only one may be used due to field conditions or timing etc. – as such they record which techniques could have been used for a given area, rather than indicate which of those was actually used (which is subsequently recorded in a geophysical report). A study of the licences indicates that magnetometry was the most frequently used geophysical technique in Ireland, and that generally, the use of other techniques followed the UK trend, with electrical resistivity being the second most commonly used technique, followed by magnetic susceptibility. Historically there has been very little use of Ground Penetrating Radar (GPR) and Electromagnetic Induction (EMI) in Ireland. The widespread use of magnetometry has, as noted above, reflected its speed of use over large areas and the assumption that it could detect a wide range of archaeological features in Ireland.

Given the smaller population (and population density) of Ireland, it is unsurprising that the size of geophysical survey areas is smaller than the UK. However, it is noteworthy that the difference in development and pre-development prospection between the two countries represents a scale jump. The average size of a geophysical survey area in Ireland is 5.2 ha and whilst developments rarely exceed 60 ha, the largest assessment in the country was limited to 220 ha in size. In England development sites often exceed 60 ha and regularly are many 100s of ha in size[29].

An economic boom in the 1990s resulted in an increase of survey area sizes that prompted a pragmatic approach to the evaluation of 'large' areas. At this time the technological advances were unable to provide fast and reliable survey over large areas and a cut-down approach to prospecting for 'hotspots' became prevalent. The common use of scanning in both Ireland and the UK was due to its ability to rapidly identify strong magnetic contrasts along 10m spaced transects that sampled 10% of a survey area. Scanning was approximately 10 times faster than a traditional (1m × 0.25m) detailed magnetometer survey using a single probe, and 5 times faster than a dual-probe system, making it a very cost-effective method in comparison. There are few published references to unrecorded magnetometer scanning but the method has been used in Ireland following its frequent use in commercial UK assessments[30]. Bonsall (2014) has recently questioned the usefulness of the method in Ireland, after analysis suggested that on the predominantly sedimentary geology of Ireland, a 71% level of failure can be expected when using scanning to identify archaeological sites. The research calculated probabilities for the detection of commonly excavated types of archaeological sites on Irish road schemes[31], based on the outcomes of legacy geophysical and excavation data:

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[29] Pope-Carter, Attwood 2014; Smalley 2014; Whittingham 2014.
[30] David 1995; David *et alii* 2008.
[31] McCarthy 2010.

a) the least frequently excavated site types – ringforts and enclosures – have a moderate-good chance of being identified through scanning (58% probability)

b) the most frequently excavated site types – burnt mounds of stone – have a low-moderate chance of identification (25% probability 25%)

c) the probability of identifying other common site types were: sites >10m = 68.8%; sites <10m = 18%; ring-ditches <10m = 14.3%; pits/kilns/hearths = 31.3%.

The frequent failure of unrecorded scanning in Ireland is unsurprising given the underperformance of even detailed (1m × 0.25m) magnetometry surveys at commonly encountered low-contrast sites. This was noted particularly for large ditched enclosure features (typically enclosing nucleated settlement activity), principally caused by poor drainage due to site morphology (i.e. ring-ditches without drainage channels) and/or soils. The vast majority of archaeological sites excavated on Irish road corridors[32] were small-scale features (pits, hearths, kilns, industrial furnaces *etc.*). Users of detailed magnetometry surveys (1m × 0.25m) have experienced substantial problems in a) detecting these features and b) recognising and interpreting them as such, due to the prevalence of high-contrast cultivation furrows and variable moderate- to high-contrast background responses, which limited the recognition of those features.

Bonsall (2014) suggested that the use and adoption of European-style high-resolution magnetometer surveys (0.5m × 0.25m) would prove valuable to the identification of low contrast sites in the future. The number of sensors on an array has gradually increased over time and it is now common to have four or more magnetometers mounted on a multi-probe array[33], which reduces the benefits offered by the scanning method. In the profession as a whole the use of scanning has become *de facto* obsolete, although scanning continued to be used on Irish road schemes until 2010[34] and is still in use by some practitioners elsewhere in Ireland.

Archaeological geophysics is used in Ireland because it is believed that such investigations will add value to the process of planning and construction by identifying archaeological features at an early stage. Infrastructure projects run by the National Roads Authority will also seek value in the use of prospection techniques beyond road corridors, in order to delimit archaeological sites and activity found within the corridor. As construction outputs increase in Ireland so to do the amount of archaeological fieldwork licences issued. Between 2013-2014 there were 462-514 consents for archaeological excavations (for each year respectively), and 131-148 consents for (terrestrial or marine) geophysical surveys. These demonstrate an 11-13% increase in the number of excavations and geophysical surveys in one year and recognition that prospection techniques play a consistent role in the planning process, albeit at a much lower level than that of excavations, which are used more than 3.5 times more frequently than geophysical surveys.

Some common questions and problems

Predominant techniques

Magnetometry is the principle technique in the Republic of Ireland and the UK and this mirrors general trends across most of Europe. It is expected that magnetometry – as a passive and therefore rapid technique capable of identifying a wide range of archaeological features – will continue to be the dominant method of prospection. However, the advent of multi-probe magnetometer arrays has led to the adoption of a landscape approach for commercial detailed magnetometry surveys in the UK, where scanning has recently all but ceased[35]. Certainly recorded area magnetometer survey is clearly the most used method in both areas under discussion. Despite the willingness to depend upon this

[32] McCarthy 2010.

[33] Campana, Dabas 2011; Gaffney *et alii* 2008; Gaffney *et alii* 2012; Ullrich *et alii* 2011.

[34] Leigh 2010.

[35] ArchaeoPhysica 2012; Hancock *et alii* 2012; Roseveare 2013.

technique there are some substantive issues that require some discussion when considering the interpretation of such data; the non-uniqueness of response from archaeological features and the degree of interpretation required.

The issue of non-uniqueness has been illustrated and debated elsewhere e.g. Schmidt 2009, and there is some consensus and understanding of this limitation. This has resulted in many groups creating excellent descriptive categorisations of suites of anomalies that are linked to archaeological interpretations. Probably the first comprehensive categorisation which included a level of confidence can be seen in Gaffney *et alii* 2000; such a strategy does not circumvent the issue of non-uniqueness but creates an understanding for all parties of the likelihood of the interpretation. Perhaps of more interest now is to consider a question posed by Gaffney and Gater[36] – is it necessary to identify 'the smallest of features', rather than define 'an archaeological site'? Should geophysicists seek to identify, classify and interpret every contrast from a data set? In short, where is the line drawn on what geophysicists can and should interpret? Gaffney and Gater's comments were primarily drawn from the commercial UK experience, but they were framed within a wider context. In general terms the level of detail required of the interpretation is normally dictated by the purpose and aims of the survey and can encompass a range of questions from 'is there an archaeological site located here?' to 'is there an isolated post-hole here?'; both require different methods of data-acquisition, processing and display. Within the 2003 article this is formalised by a three tier level of investigation (Level I: Prospection; Level II: Evaluation; Level III: Investigation) which is linked to data intensity and archaeological outcomes.

To put the debate into some context, it is known[37] that the vast majority of 'sites' excavated on Irish road schemes are small scale features (pits, hearths, kilns, industrial furnaces *etc.*) and that commercially driven magnetometer assessments were found to have commonly missed pits of varying sizes, which when compared to excavated remains (admittedly with the benefit of hindsight) were clearly visible as magnetic contrasts[38]. Most surprisingly however, was that not only were pits unrecognised, but stronger magnetic contrasts from thermoremanent features – hearths and kilns – were also missed. The fact that some 'obvious' features have not translated into mappable anomalies is well known[39] and the ramifications, in terms of undermining the techniques' use, can be seen in the 'Planarch' document[40] which attempted to assess how much of a site was identified by various remote sensing techniques. While Gaffney (2009) has critiqued the Planarch approach, the Planarch document remains a salutary reminder of the limitations of the geophysical approach to detailed mapping of archaeological features.

This is a key issue that has implications for geophysical survey practice for all users and should serve as a warning to practitioners interpreting large scale magnetometer data. Why do such features go unrecognised? Small-scale anomalies may have been overlooked in favour of larger anomalies (indicative of clearer or more 'obvious' archaeological sites) when examining datasets that cover several 10s or 100s of ha, or that variable background responses (often comprised of isolated moderate- to high-contrasts) might be responsible for the limited recognition of isolated pits, hearths and kilns. It is surprising that the distinctive magnetometer response to a kiln has gone unrecognised, however such limitations are often unknowable – whilst data collection is repeatable, interpretation introduces a number of key bias' around the experience of the interpreter that are not necessarily limited to a knowledge of the local soil conditions. The nature of interpretation is that humans, no matter how experienced, sometimes get detailed interpretation of geophysical data wrong.

The improved recognition of small-scale features is particularly important for archaeology. Test trenching at development sites is capable of identifying large enclosures, just as magnetometry potentially

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36 Gaffney, Gater 2003, p. 182.
37 McCarthy 2010.
38 Bonsall 2014.
39 See Weston 2004.
40 Hey, Lacey 2001.

can; however test trenches are not able to identify small and isolated features that may be located beyond the trench limits. Geophysical surveys can add value and offer substantial benefits over intrusive methods by identifying these small scale features. In order to do this, the 'standard' magnetometer survey resolution used on the vast majority of commercial projects in Ireland (1m × 0.25m) will need to be improved.

Enabling high density surveys

As predicted by Gaffney[41], many practitioners (in both the commercial and research arena) are now utilising high-precision GPS and a wide variety of geophysical instrumentation. The benefits of using articulated- or pedestrian-powered methods of data-acquisition with a cart have been highlighted by various case studies for magnetometer[42], earth resistance[43], electromagnetic[44] and GPR surveys[45]. Until recently it was legitimate to ask what the uptake of cart systems was in every day survey? The progress had been 'organic' but there has, in recent years, been a significant acceptance of these systems within commercially focussed groups. Within the administrative county of Norfolk (UK) guidance now requires a) cart based data acquisition b) sub-metre traverse intervals and c) RTK GPS locational data, for all commercial magnetometer surveys as a minimum standard[46] and it is likely that other regions will adopt similar practices.

In Ireland the acquisition of data using cart systems was first achieved by commercial consultancies in Ireland rather than research bodies. The size of some key infrastructure projects, such as a 182 ha magnetometry assessment of the M20 Cork-Limerick Motorway, acted as a driver for commercial companies to adapt their existing dual walking frame instruments to articulated carts[47]. Subsequent assessments also benefited from GPS-acquired magnetometer systems[48], and high resolution (0.5m × 1m) EMI data collection[49], using GPS-acquired cart-mounted instruments. Infrastructure projects in Northern Ireland have also exploited cart-based gridlessly-acquired EMI instrumentation to assess 34 ha of poorly drained land[50].

It is significant that the first research-driven surveys using carts only did so after initial successes in the commercial arena. Although yet to be published, the results of high resolution magnetometer surveys (16 sensors at 0.25m spacing acquiring gridless data on an ATV-powered cart) by the Roman-Germanic Commission of the Deutsches Archäologisches Institut and the Irish Discovery Programme, over known high-status sites (Freestone Hill, the Hill of Tara and the Dowth Estate at the Brú na Bóinne UNESCO World Heritage Site) carried out in 2014 are highly anticipated. The methodology of data acquisition might, depending on its outcome, set a benchmark for research prospection surveys in Ireland – however, the dense acquisition of 0.25m spaced data may be a challenge to both commercial practitioners as well as researchers without access to extensive instrumentation and data processing facilities. This research based strategy has been relatively common on mainland Europe, particularly via the LBI case studies such as the Stonehenge Hidden Landscapes Project[51]. The increasingly large scale of developments (combined with often short survey windows required by rapid construction projects), will ultimately persuade most Irish contractors to widely adopt the new cart-mounted technology.

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41 Gaffney 2008, p. 331.
42 Doneus *et alii* 2011; Gaffney *et alii* 2012.
43 Dabas 2009.
44 Simpson *et alii* 2009.
45 Biwall *et alii* 2011; Linford *et alii* 2010; Linford *et alii* 2011; Trinks *et alii* 2010; Verdonck, Vermeulen 2011.
46 Hamilton 2014.
47 Harrison 2012.
48 Nicholls 2013.
49 Bonsall, Gimson 2015.
50 Gimson, Bonsall 2014.
51 Gaffney *et alii* 2012.

Large-scale data-acquisition: new challenges for bigger data

A key issue for the ever increasing size of geophysical survey areas is data processing. Whilst carts, multiple sensors and GPS enable the acquisition of larger and larger areas in shorter time-scales, significant time is still required to process and interpret data to an appropriate level. A number of commercial practitioners currently offer a new way of delivering data processing via third-party services, who process large amounts of data, and/or assist in the presentation and visualisation of that data. Geocarta, for example, offer online web services to securely transfer and display data in an open-source Web-GIS between project partners 'regardless of [data] size' (http://www.geocarta.net/html/Web-Sig.html). GeodataWIZ offer advanced processing, metadata and visualisation of data transmitted online (http://www.geodatawiz.com/). These services, and others, effectively outsource a large amount of post-survey work and reduce the reliance on both software and hardware requirements for a survey unit.

Such outsourcing results in a noticeable disconnect between practitioners acquiring data in the field, data processors, data interpreters and report writers, one of which might be expected to manage the overall project. 10 years ago, such roles would have been filled by staff within a single company (and in some cases, only a handful of individuals present during the 'lifetime' of a project), whereas today, a geophysical report may be the product of several individuals collaborating not only in different work-space environments, but also on different continents. Such an approach requires rapid and seamless collaboration between a number of specialists, requiring clear communication of the project aims, duration, budget and timescale. This may be further complicated by the size of digital data (as well as images and/or animations) and the technical infrastructure (i.e. file sharing over the internet and cloud storage) required by each of the disparate experts in various locales. Many of these challenges have already been experienced in the wider world of exploration geophysics[52], from which lessons can be learnt. A particular difficulty noted was the challenge faced by researchers attempting to collaborate in the midst of changing standards, evolving tools and the lack of a common software infrastructure, which is also true for archaeological geophysics. Erlebacher *et alii* noted the absence of user-friendly software and 'transparent middleware able to handle large data sets in a collaborative mode', which can similarly be levelled at our own discipline; despite significant developments in some areas of archaeological geophysics, much of the high-end software remains an in-house speciality. Whilst there is currently little evidence that commercial software solutions will come online in the short-term, we are encouraged by the outsourcing options that could be exploited.

There are positives to take from this, for example an expertise in coding and data processing are increasingly valued by the profession. However there are also potential pitfalls such as the loss of local (on-site) knowledge of subtle field conditions that may not be fully appreciated or characterised in a final report or publication or the loss of (often) tacit knowledge due to staff transfers, retirement and poor health etc. These challenges once again emphasise the importance of a high-quality archive (of both data and the local survey environment) and the need for continuing education in areas that have been traditionally beyond the remit of 'conventional' geophysicists who simply 'collect' data.

The need for flexibility and feedback

Following a review of legacy data derived from geophysical surveys and excavations on road schemes[53], some procurers in Ireland are now moving away from the UK model that they previously adopted – which favoured magnetometry (and scanning) over other instruments and largely relied solely upon that technique rather than employing multiple methods. Given the wide variation of archaeological site types and soils in Ireland, a *reliance* upon magnetometry was deemed to be unsatisfactory, whilst

[52] Erlebacher *et alii* 2006.

[53] Bonsall *et alii* 2014.

also conceding that magnetometry is actually the most suitable technique for identifying the *majority* of buried archaeological features in Ireland. The exclusive use of magnetometry was not the most significant problem; it was the manner in which that technique was used – in the past, magnetometry (both detailed and scanning) assessments were applied to survey areas (large and small) without due regard to geology, soil or archaeological site type. It is evident from the general acceptance of magnetometry as the primary technique in the UK, and particularly in England, that a significant move away from this technique is unlikely and unwarranted. However, all the reviews[54] based on surveys in England project some notes of caution. This is particularly true of magnetically low contrast archaeological features on poorly draining soils and these may require alternative strategies including high resolution methods and non-magnetic techniques.

A key finding of Bonsall's (2014) review of legacy data exemplifies this issue – 35% of large ditched enclosures were not identified at all by standard detailed (1m × 0.25m) magnetometry surveys. The majority of those were located on poorly draining soils that allowed rainfall and other water run-off to stagnate and silt up in circular ring-ditches, with limited opportunity (if any) for natural drainage. Such waterlogged conditions will impede the magnetic susceptibility enhancement of anthropogenic soils[55] and have led to very low contrast anomalies (or no-contrast at all) that could not be visualised in magnetometer data. Whilst high resolution (0.5m × 0.1m) magnetometer surveys can offer an improvement in these situations, they can be an inappropriate choice of technique when earth resistance or EMI apparent electrical conductivity surveys are better suited to areas of poor drainage – where low magnetic contrasts (or an absence of contrasts) can be expected for earth-cut features. This logic must be kept in mind given that more than one-third of Ireland has poor to imperfectly drained soils[56] that are capable of impeding the magnetic susceptibility of poorly draining archaeological features. It is believed that the recent success[57] of electromagnetic surveys on these types of soils should lead to a higher frequency of use for the technique in the future. The acquisition of co-located and multi-depth apparent electrical conductivity and apparent magnetic susceptibility data will increase the chances of identifying different types of archaeological features. It is a small step in the argument to suggest that the use of multiple techniques (including magnetometry) will be advantageous in poorly drained areas; magnetometry is still the most effective for detecting small-scale thermoremanent features.

Evidently in order to choose the most appropriate technique we need better and more consistent feedback. While that is not a regular occurrence[58], we benefit as a profession from being self-critical and thereby avoiding external criticism such as Hey and Lacey (2001). This will in turn foster better interpretation of geophysical data.

Conclusion

Archaeological geophysics is a relatively young sub-discipline in both the UK and Ireland. In this paper we have demonstrated a communality of approach that, in the case of Ireland, was based around technical delivery rather than context specific knowledge. Within recent years the prevailing view is that a greater understanding of local conditions, particularly the geological background, is required to inform on the best instrument(s) to be used in a particular survey. While this is apparent in Ireland, the UK has not been impervious to challenges with respect to low magnetically-contrasting environments. A result is a better focused set of questions that can fulfil the industry standard requirements for geophysical survey. In general this means the potential for different techniques and, particularly in Ireland, multiple techniques.

[54] Hey, Lacey 2001; Jordan 2009; Knight *et alii* 2007.
[55] Weston 2004.
[56] Gardiner, Radford 1980.
[57] Bonsall *et alii* 2013.
[58] See Boucher 1996.

Despite these local divergences, both areas are susceptible to Europe wide and even global trends. A case in point are the rapid changes in data collection seen over the last five years and these force us to reconsider how we implement survey methods in the future. It is clear that guidance documents, be they regional or continental, must remain current and must be a formed of a consensus, even if we do not agree with all aspects of them. Recent changes in data acquisition and survey density also remind us that we must avoid specifications that are irrelevant or backward looking. It is evident that the use of magnetic scanning (and possibly magnetic susceptibility survey?) illustrates the need to update advice and guidance.

It can be argued that in both Ireland and the UK, geophysical survey for archaeological purposes is buoyant, despite the challenges of the recent recession. The re-evaluation of the discipline, partly as a result of the economic downturn has had a number of consequences; while there is an inevitable and unwelcome loss of experienced operators as a result of the initial drop in evaluation style work, the efficiencies that result from the adoption of cart data collection technology have provided increased archaeological benefits. Survey of larger areas, with greater sample intensity and locational control, are very welcome and will embed geophysical techniques more firmly into the archaeological tool kit. While local differences will emerge between Ireland and the UK, the technological changes that geophysical surveyors have embraced in these areas will mean that geophysics is unlikely to be divorced from archaeology or archaeologists at any time in the near future.

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