Themata 5 E-learning Archaeology, the Heritage Handbook

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E-learning Archaeology

the Heritage Handbook

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by Robert Hook, with cooperation of Arkadiusz Marciniak & Włodzimierz Raczkowski

MSCO Introduction

This module is intended to help archaeologists, particularly curators, consultants and project managers, to better understand and engage with the techniques of geophysical survey. Geophysical survey in archaeology continues to flourish. The techniques are finding an increasing role in the presentation and interpretation of archaeological sites, in contributing to archaeological and forensic research, and in helping to satisfy the demand for media coverage of archaeological subjects.

\> ***Animation***

Geophysics in archaeology comprises a range of methods. As regards applied physic rules, it is divided into passive and active methods.
Passive methods.
They are based upon passive registration of existing properties of archaeological features.
Magnetic survey.
It is based upon measuring of changes in intensity of a total natural earth magnetic field aimed at identifying anomalies caused by existing archaeological structures.
Active medthods.
They are based upon picking up certain physical traits generated by electric and electromagnetic waves.
Earth resistance survey.
Earth resistance survey is based upon measurement of earth resistance generated by a system of current electrodes. It is required to generate an electromagnetic field in order to measure earth resistance. This procedure is based upon the phenomenon of the reflection of impulses from archaeological objects, parameters of which are registered by the receiver.

→ LU Geophysical techniques and instruments

by Robert Hook with cooperation of Arkadiusz Marciniak & Włodzimierz Raczkowski

SCO The survey grid

Geophysical fieldwork relies on the presence of an accurately plotted network of control points extending across the area to be worked on and this is usually referred to as the survey grid. An internally accurate and correctly georeferenced grid is crucial to all subsequent survey. Recent developments involving mobile sensor platforms incorporating real time global positioning system (GPS) sensors mean that it is no longer always necessary to establish a conventional grid of fixed markers over the surface of the area to be surveyed.

SCO Magnetometer survey

Magnetometer survey offers the most rapid ground coverage of the various survey techniques and responds to a wide variety of anomalies caused by past human activity. It should thus be the first technique considered for detailed survey of an area and other, slower, techniques should usually follow afterwards, targeting smaller areas of interest identified by the wider magnetometer survey.

Mangetometer survey can identify thermoremanently magnetised features such as kilns and furnaces as well as in-filled ditches and pits and areas of industrial activity (both recent and ancient). Unless composed of materials that contrast magnetically with the surrounding soil (eg bricks carrying a thermoremanent magnetisation), magnetometers do not usually detect wall footings directly and in this regard it is complemented by earth resistance survey.

\> ***Animation***

Instrumentation

Fluxgate gradiometer

This instrument combines sensitivity of the order of 0.1nT with lightweight design and rapid measurement rates.

Alkali-vapour magnetometer

It may also be named optically-pumped or caesium magnetometers (although the other alkali metals – potassium and rubidium – can also be used). They offer sensitivities of the order of 0.05 to 0.01nT and can make measurements at similar rates to fluxgate systems.
The main practical difference between the two types of instrument is that an alkali-vapour magnetometer measures the total absolute magnitude of the local magnetic field, while a fluxgate gradiometer measures the relative difference between the magnitude of the vertical

component of the local field measured by two sensors positioned one above the other (separated typically by a distance of 0.5 or 1m).

In general, alkali-vapour instruments are more sensitive (Becker 1995) but it is usually necessary to mount them on some form of mobile platform or cart – thus reducing sources of random measurement errors – to take full advantage of their enhanced sensitivity.

It may be remarked that other types of magnetometer are also available (eg proton, Overhauser); however, their use for routine survey would require special justification.

SCO Methodology and units of magnetic measurement

Magnometer survey offers the most rapid ground coverage of the various techniques and responds to a wide variety of anomalies caused by past human activity.

> *Animation*

Field conditions may dictate the type and configuration of magnetometer that it is most practical to employ. A cart-based system may be of limited use in a confined area. Gradiometers discriminate more strongly than total-field systems in favour of anomalies in close proximity to the sensors. This property can limit the maximum depth at which features can be detected and total field systems are perhaps more suited when remains are expected to be deeply buried (eg alluviated environments).

Given the relative rapidity (and thus cost-effectiveness) of modern magnetometers, the preference should be for a detailed magnetometer survey of the entire area subject to evaluation. Measurements are recorded at regular, closely spaced, intervals along each traverse. This is usually achieved by setting the instrument to take readings at fixed time intervals and using an audible time signal to ensure an even pace, or by recording fiducial markers at regular distances so that variations in pace can be subsequently corrected for. However, as noted earlier some recent magnetometer systems can integrate directly with a GPS system to log the position of each measurement directly and obviate the need for a pre-established survey grid.

For detailed area survey it is strongly recommended that the maximum separation between measurements along a traverse should be no more than 0.25m.

Magnetometers measure changes in the Earth's magnetic field and the SI unit of magnetic field strength is the tesla (T) (Moskowitz 1995; Payne 1981; Taylor 1995). However, this unit is inconveniently large with respect to the weak magnetic anomalies caused by archaeological anomalies, so magnetometer measurements are normally quoted in nanotesla (nT) where 1nT = 10-9T. Gradiometers measure the difference between two magnetic measurements separated by a fixed distance. Units of magnetic field gradient nT/m might be deemed appropriate, but a true gradient is only measured when the decay in magnetic field strength is linear between the two sensors and this is generally not the case unless the nearest causative anomalies are at a distance much greater than the sensor separation.

SCO Earth resistance (resistivity) survey

While research continues to produce many refinements to the electrical prospecting technique, for most field evaluations standard earth resistance survey is required. Details of theory and field procedures have been extensively aired in the literature and instruction manuals.

> *Animation*

The rate of coverage using earth resistance survey is limited by the need to make direct electrical contact with the ground by the insertion of electrodes. A number of developments, such as mounting electrodes on a fixed frame as well as automated measurement and data recording have greatly increased the speed at which this can be done. Nevertheless, the rate of ground coverage typically remains about half that possible using a magnetometer, so survey costs per unit area are generally higher. It is thus particularly important that earth resistance survey is used economically and in circumstances suited to its particular strengths.

Earth resistance survey can often identify ditches and pits because they retain more (or sometimes less) moisture than the surrounding soil. However, in many instances the chances of detecting these with a magnetometer are higher and this more rapid technique should be preferred. Exceptions might be considered in areas of extreme magnetic interference or where soil and geological conditions are not conducive to the development of anthropogenic magnetic anomalies. Conversely, earth resistance survey should be favoured where building foundations and other masonry features are suspected, for instance over ecclesiastical and other medieval buildings, defensive works, etc. When applying earth resistance survey there should already be a strong presumption that such features exist within the survey area. In this sense, earth resistance is not a primary prospecting technique and its application in many evaluations will be secondary.

Magnetometer and earth resistance survey complement each other and, for large evaluations, it is often best to assess the area magnetically first, followed by selected earth resistance survey of areas identified as likely to contain building remains.

The most popular systems make measurements automatically when electrical contact is made with the ground and can automatically record readings to on-board electronic memory. The Geoscan RM15 system is particularly versatile, with optional modular extensions creating a frame mounting up to six multiplexed electrodes. Under favourable conditions several measurements at different electrode separations may be made each time the frame contacts the ground; one application of this facility is to speed data collection by collecting two parallel traverses of data simultaneously. Recent innovations have allowed earth resistance meters to be used with cart-based platforms on which spiked wheels replace the traditional electrodes. These platforms offer faster rates of ground coverage and it is often possible to mount other instruments, such as GPS receivers or magnetometers, for simultaneous coverage.

SCO Methodology

The type and standards of grid layout are the same as for magnetometer survey. For area evaluation surveys the twin electrode (or twin probe) configuration (Clark 1996, 38) will normally be employed. Using this configuration, the vast majority of buried features are detected as simple single-peaked anomalies. Cart-based systems may, alternatively, use the square array, which has similar response characteristics but avoids the need for fixed remote electrodes.

> Exercise: Fill in the blanks

> *Animation*

Clark considers optimum electrode separation for the detection of features buried at different depths. However, it is rare that the precise burial depth of archaeological features is known in advance and, for the twin electrode array, a mobile electrode separation of 0.5m is now standard and detects features up to 1m beneath the surface. Where deeper overburdens are expected, a separation of 1m is commonly employed. Electrode separations much greater than 1m tend to result in multiple-peaked anomalies and unacceptable loss of definition. At the standard interval it should be possible to cover about 0.75 to 1ha per day.

Different geologies, soils, and differences in soil moisture and chemical content can all affect the magnitude of the earth resistance anomaly caused by a buried feature; the optimum range setting and measurement resolution will therefore usually have to be determined for each site at the time of the survey. Under typical UK conditions measurements might range between 0 and 200 ohms in which case a resolution of 0.1 ohm would be suitable. However, in dry conditions much higher earth resistances can be encountered and a measurement range of 0 to 2000 ohms might be needed, in which case a resolution of 1 ohm would be acceptable.

Area survey with the twin electrode system involves positioning two fixed remote electrodes at a distance of some 15m to 30m (~30 times the mobile electrode separation) from the mobile frame and connected to it by a cable. As the survey progresses it will become necessary to reposition the remote electrodes so that the survey can continue and care should be taken to 'normalise' measurements between the new and old remote electrode positions to avoid discontinuities in the measured survey data.

SCO Ground penetrating radar

Collectively, the term ground penetrating radar (GPR) has been applied at an administrative level within Europe to all methods of geophysical survey utilising electromagnetic radiation in a range from 30MHz to 12.4GHz to image buried structures. This encompasses a wide range of applications and the term is used to describe the more common, commercially available GPR systems suitable for archaeological surveys.

> *Animation*

GPR can often be more costly than conventional methods of area geophysical survey (eg magnetic and earth resistance techniques), but does present some unique capabilities to provide estimates of the depth to target features and, under suitable conditions, present three-dimensional models of buried remains. GPR can also be the only practical method to apply on certain sites, or within standing buildings, where the presence of hard surfaces and above-ground ferrous disturbance precludes the use of other geophysical techniques. However, the resolution of vertical stratigraphy is limited and highly dependent on both site conditions and the instrumentation deployed.

A wide range of site surfaces may be considered for GPR survey, including concrete, tarmac and even fresh water, although the technique is limited by the attenuation of the signal in conductive media.

In practice, this will largely be determined by the concentration of clay and the moisture content of the soil at the site. Highly conductive media, such as metal objects or salt water will prove largely opaque to the GPR signal. Strong reflectors in the near-surface will also reduce the energy transmitted to immediately underlying targets and this

may include the local water table (or other near-surface interface).
For normal ground-coupled antenna, good physical contact with the site surface is necessary to ensure adequate coupling of the radar energy with the soil.
As far as possible, vegetation and any other surface obstructions should be removed from the site prior to the survey. Air-launched antenna may prove useful for surveying delicate architectural features (eg plaster mouldings, wall paintings or mosaic pavements) when it is desirable to have no physical contact between the instrument and the surface under investigation.
Many site-specific variables must be considered when using GPR, but in general it will respond to a wide range of archaeological features, and is often successful over sites where earth resistance survey has proved fruitful (eg. presence of masonry walls, void spaces, etc).
GPR is sensitive to the interface between differing materials and some target features produce highly distinctive GPR anomalies (eg hyperbolic responses from point reflectors). However, the identification of complex material properties, for example distinguishing either human or animal bone from the surrounding substrate, is presently considered to be beyond the capabilities of the technique under typical field conditions.
While the use of GPR for detailed large area surveys (>1ha) has increased it is often applied as a complementary technique, following the acquisition of magnetic or earth resistance data, to target specific archaeological anomalies identified over a more limited area of the site.
Care must be taken to ensure that GPR survey is appropriate to a site, particularly if it is the only technique to be applied. The proximity to sources of radio-frequency (RF) interference that may affect the data quality – such as mobile telephone transmitter base stations or the radio modem of an on-site differential GPS system – should be considered.

SCO Instrumentation and methodology

GPR systems utilise an electromagnetic source, generated by a transmitter antenna on the ground surface, and record the amplitude and time delay of any secondary reflections from buried structures. These secondary reflections are produced when the GPR pulse is incident upon any media with contrasting conductivity (s) or (dielectric) permittivity (e), or both, to the medium above.

The majority of archaeological materials and soils are semi-transparent to the GPR signal and this is able to penetrate to some depth, creating a series of secondary reflections from buried objects distinguished by an increasing time delay. The resulting time-amplitude data is displayed as a two-dimensional profile with the X-axis indicating the horizontal location of the antenna on the ground surface and the Y-axis representing the increasing time delay (depth) from the initial impulse.

The recorded delay represents the total time required for an incident pulse to travel from the transmitter to the target and then for the reflection to return to the receiver. This dual pathway is known as a two-way travel time and can be converted to provide the approximate depth of buried targets where an accurate estimate of the sub-surface velocity can be made.

GPR systems consist of an antenna unit housing the transmitter and receiver, an electronic control unit, a data console and a power supply.

> There are three main modes of GPR data acquisition:

> ***Animation***

Scanning
GPR instruments provide a real-time visual display of the recorded data and may be used to locate known or suspected features, perhaps during invasive works in the field.
Individual recorded profiles
Single profiles may be recorded over the suspected location of known features or to investigate anomalies identified by other geophysical techniques; for example, to estimate the depth to a particular target or to determine the course of a linear feature over an extensive area where the route may be interpolated between more widely spaced traverses.

Detailed area survey
Area survey over a regular grid of closely spaced traverses is strongly recommended for detailed GPR investigations. Under typical conditions for a 500 MHz centre-frequency antenna any traverse spacing above 0.25m will be spatially aliased. However, as such densely sampled surveys are difficult to achieve over large areas unless a multi-channel instrument is available, a traverse separation of 0.5 m is suggested where spatial aliasing will not be detrimental to the interpretation of the target features.

SCO Electromagnetic methods

A range of geophysical instruments make use of electromagnetic waves, distinguished by the frequency and duration of the source that they utilise. While such a broad definition should include GPR, magnetic susceptibility meters and metal detectors, these special cases are considered individually elsewhere. This section therefore considers only inductive EM instruments, also known as 'slingram' or conductivity meters. These emit a continuous low-frequency (<300 kHz) EM signal from a transmitter coil, that will in turn generate a secondary field within any electrical conductors present in the near-surface. A separate tuned receiver coil records the modulated signal, where it is found that the in-phase component is proportional to the magnetic properties of the subsurface and the out of phase, or quadrature, response to the electrical conductivity.

While initial research demonstrated the ability of EM instruments to identify archaeological features, the technique is not, at present, widely used in the UK for archaeological evaluation. In principle, as the coils of an EM instrument do not necessarily have to make contact with the ground surface they offer the advantage of rapid field data acquisition, combined with the simultaneous collection of magnetic and conductivity data-sets. However, considerable inter-site variability of the EM response may be encountered, depending on underlying geology and soils, requiring calibration against more conventional methods of geophysical survey. EM instruments are also sensitive to conductive objects in the near-surface that may preclude their use, for example metal fences, rubbish, buried pipes, etc, and to electrical interference from both cultural (eg power lines) and atmospheric sources.

For most archaeological applications an EM instrument with an inter-coil spacing of approximately 1m will suffice, collecting data at a reading interval of 1m × 1m. Field operation and calibration will vary between instruments, but it should be possible to convert the recorded signal (often expressed as parts per thousand or ppt) to units of apparent conductivity in millisiemens per metre (mS/m) and volume magnetic susceptibility (dimensionless).

> SCO Exercise

→ LU Geophysical survey and archaeological practice *by Robert Hook with cooperation of Arkadiusz Marciniak & Włodzimierz Raczkowski*

SCO Geophysical Survey

Geophysical survey should be thought of as one of the main techniques of site evaluation and its potential contribution must always be considered in each instance where development is proposed.

The purpose of the following section is to provide advice that will be helpful to archaeological heritage staff in determining whether or not a geophysical survey is required in a particular instance, and, if so, what techniques and methodologies may be the most useful to consider.

> Exercise: Which term is the odd one out? Click on it and check your answer

> ***Animation***
> The choice of survey method(s) will vary with the site conditions, logistics and time constraints particular to each separate evaluation project. Adequate time should be allowed for the geophysical survey to be undertaken and reported on once this has been identified as a preferred evaluation technique.
> Geophysical survey is of course one of many possible approaches to the evaluation of archaeological potential, and its contribution must be appropriately balanced with others so as to optimise the project outcome. A typical combination might include data derived from: aerial photography, map regression, geophysics, field walking and test-pitting. Ideally, data-sets such as these will be analysed and interpreted within a GIS environment. It is obvious too, that within this broad concept of integration, geophysical survey itself offers a variety of approaches that can and should be used together to their mutual advantage. Choosing an appropriate survey strategy is never straightforward: it will depend upon the interplay of many factors, and will therefore vary from one site to another.
> It is rare that any one strategy can be singled out to the exclusion others, and different surveyors may well arrive at different procedures, each of which will have merit for different reasons.
> All projects need to give consideration to the full breadth of techniques that might be applicable to an evaluation, and to develop a specification that maximises their joint potential. For example, magnetometer survey may provide a distribution of pits, ditches and industrial features, but it will usually be necessary to combine this with more targeted earth resistance survey and/or GPR to identify building foundations. For the purposes of evaluation alone, however, it will often be sufficient for the choice of techniques simply to give an indication of the archaeological potential.

SCO Geophysical survey in different archaeological contexts

> Exercise: click on each picture to read its description and choose geophysical survey and archaeological contexts bottoms

> ***Animation***

Urban sites

The depth and complexity of most urban stratigraphy, closely constrained by modern intrusions, metallic contamination, services and adjacent structures, provides a near insuperable deterrent to successful geophysical survey. An exception to this prognosis is when the survey is intended to detect the remains of industrial archaeology, which can often cause distinctive and strong anomalies. Tightly constrained sites in heavily built-up areas do not usually offer suitable conditions for geophysical techniques, with the possible exception of GPR. Magnetometer survey over tarmac is possible only in exceptional circumstances. It may be possible over other types of paving but only in relatively unusual circumstances when no elements of the paved surface are strongly magnetic. Earth resistance survey is not possible over tarmac but electrical sections can be collected over other types of paved surfaces using plate electrodes and conductive gel or bentonite clay.

Open sites

On open sites – rough ground, verges, gardens, allotments, playing fields, smaller parks, cemeteries, etc – the more traditional techniques can be applied, although experience shows that good results, while sometimes possible, are not often obtained. Surface obstruction or ground disturbance can prohibit sufficient survey coverage and mar the survey response, or both.

Geophysical survey will not be justified in many circumstances, although magnetometer, earth resistance and GPR methods can be invoked when encouraged by specific expectations (eg of kilns, voids or wall foundations). Decisions on survey method and the interpretation of results must depend on as thorough a knowledge as possible of former land use. Trial trenching, coring and/or test pitting may well be a preferable approach in a majority of cases.

Cemeteries

There are considerable difficulties in the detection of prehistoric cemeteries or individual graves. None of the techniques such as earth resistance traverses or GPS can easily detect individual inhumation graves or cremations owing to their relatively small scale and lack of physical contrast between fill and subsoil. Individual cremation burials may be detectable magnetically but the response is not normally distinguishable from background variations (nor, indeed, from anomalies from other types of feature of similar dimensions and magnetic characteristics).

Graves, cremations or cemeteries can therefore only be detected in very favourable conditions, often only indirectly, and when there is already good reason to suspect such features to be present. Geophysical evaluation, particularly over poorly known ground, will therefore easily overlook this important category of feature.

Stone lined coffins or cists may be detectable with earth resistance, or with GPR, using a narrow sampling interval (0.5m × 0.5m for earth resistance survey; 0.05m × 0.5m for GPR), but ordinary graves in rural situations are perhaps best sought with a magnetometer, also with a narrow sampling interval. The magnetometer response to ferrous items, chariot fittings or individual weapons may give away the presence of graves, but it is frequently impossible to tell the difference between these responses and those from irrelevant ferrous items.

Alluvium

The detection of archaeological features at depths of >1m, whether covered by alluvium, colluvium, blown sand, peat or other material remains a major problem. There can be no preferred recommendation until the merits of each individual site or area have been assessed. A pilot survey, linked with coring or test pitting can be invaluable in the subsequent development of a preferred full evaluation. Depths of alluvial cover, magnetic susceptibility values for the major sediment units, and local geomorphology will all have a significant bearing.

Magnetometer survey should usually be the method of choice. Depending upon relative magnetic susceptibility values of the fills of smaller features, alluvium and subsoil, and the depth of burial, archaeological sites may be detectable up to 1m down. The deeper the archaeology, however, the less likely to be resolved are small and poorly magnetised features. Magnetic anomalies show a tendency to broaden as they become more deeply buried by alluvium. While larger ditches, pits, hearths and kilns, etc may well be detectable at depths of 1m or more, the signal from smaller features will be too weak; many types of site – especially pre Iron Age ones and those without significant magnetic enhancement (eg most 'ritual' and many ephemerally occupied sites) – can be missed altogether.

Magnetometer survey should preferably target shallower alluviated areas, and their margins, and should, if possible, attempt to 'follow' detected features into areas of deeper alluvial cover, thereby enabling an estimate of 'fall off' in local detectability to be made. Survey with alkali-vapour magnetometers, which have an increased sensitivity over fluxgate instruments, makes it possible to detect weaker signals from more deeply buried features. For the time being, the use of alkali-vapour magnetometers should at least be a consideration in evaluations of alluviated areas where magnetic targets are concealed at depths of >1m. However, close attention to available aerial photographic and microtopographical evidence is always essential.

If magnetometer survey is ineffective there may be some justification in attempting earth resistance survey over suspected structural remains, but problems of resolution at depth (>1.0 m), as well as the costliness of extensive survey, can be prohibitive. Electrical sections, using widely spaced electrodes (>1m) can be of value in plotting the larger-scale features of the sub-alluvial surface, although GPR, under suitable conditions, is probably a more flexible and rapid method.

In summary, alluvial and other types of superficial deposits present serious difficulties for geophysical prospecting. These are accentuated at depths in excess of a metre. For large areas, a pilot survey can be conducted, testing the suitability of various techniques, although the emphasis may often turn out to be on magnetometer survey. Other survey techniques, such as GPR, can be used more selectively but at present none can be recommended as an adequate general technique in these conditions.

Wetlands

The problems of depth of burial, as in case of alluvium, are accentuated by waterlogging. The only technique that at present seems to offer any potential is GPR over low mineral content peat.

At low frequencies (eg 100MHz) the peat/mineral interface of peat basins is detectable at depths up to about 10m, and reflections have also been recorded from substantial objects such as bog oaks. Magnetic susceptibility readings on waterlogged material can be suppressed by chemical changes.

Geophysical techniques can, as yet, have little part to play in wetland evaluation. Structural remains (such as pile dwellings, trackways, etc) in organic sediments, in particular, are often undetectable. Traditional dry land geophysical techniques are best attempted in areas of relative dryness and shallow overburden ('islands' or wetland margins) and features so detected may then have some indirect bearing on the likely location of significant sites elsewhere obscured.

Road and pipeline corridors

Linear developments are complicated by the large and extended area of land affected and by the variety of geological and soil conditions through which the route will inevitably pass.

Geophysical survey may often play a unique role in the evaluation of archaeological remains threatened by linear developments and should be conducted at an early stage in the planning process, when consideration of the results may mitigate the route of the development to take account of significant archaeological features.

SCO Archaeological practice

Geophysical survey thus has a crucial role, and although the general rules of survey as outlined elsewhere in these guidelines apply, the special problems of survey logistics, and the choice of an appropriate balance of survey methodology, suggest that a separate consideration is needed. It is stressed that the following recommendations are general and do not attempt to set out a rigid procedural blueprint.

> ***Animation***

The following specific points should be addressed:

1 The proposed geophysical methodology should be appropriate for the location of archaeological remains along the route of the linear development; note that a single technique may not be suitable for the entire length of the proposed development.

2 Detailed area survey over a closely sampled grid is to be preferred over any unrecorded (eg magnetometer scanning) or low sample density recorded methods (eg topsoil magnetic susceptibility). Where circumstances dictate that such methods must be used, single long traverses should be avoided.

3 The area covered by such detailed survey should be sufficient to encompass the entire easement of the development and any additional areas where damage to underlying archaeological deposits may occur (e.g. planned access routes).

4 If possible, the survey transect should also be of sufficient width to characterise adequately the archaeological potential of significant geophysical responses, particularly linear anomalies, traversing the route.

5 The recent introduction of multi-sensor geophysical instruments and platforms, combined with GPS, has significantly increased the rate of field data acquisition. As a result, areas that in the past would have been considered so large that they could only be partially sampled, are often now amenable to rapid and cost-effective detailed magnetometer survey in their entirety.

Providing no overriding geophysical contra-indications exist (e.g. unfavourable geology or soils, preponderance of modern ferrous interference, etc.), then magnetometer survey should provide the most cost-effective method of evaluation. A sample interval of at least 0.25m × 1m should be used, which can be collected rapidly in the field using a multi-sensor instrument. Other geophysical techniques would not usually be deployed blind over large parts of a linear development. The width of the corridor to be evaluated using geophysics will depend on the particular linear development in question. However, in the case of pipeline developments, given the typical easement width and the area excluded from subsequent survey by the presence of the ferrous pipe or embankments, a minimum linear transect width of 30m would commonly be suitable. For road corridors the maximum width is normally between 40m and 100m, and this should always be completely covered.

> SCO Exercise

→ **LU** Geophysical survey and planning *by Robert Hook with cooperation of Arkadiusz Marciniak & Włodzimierz Raczkowski*

SCO Geophysical survey and planning

There is widespread necessity for field evaluation as a preliminary stage in the planning process. The potential contribution of geophysical survey should be considered in each instance where development is proposed. As geophysical survey will often be a crucial element in site evaluation it is most important that it should be correctly integrated within briefs and specifications and within subsequent project management. Prior to fieldwork, the geophysical survey requirements must be integrated within a written statement (the project design, specification, written scheme of investigation, or survey contract). This must include an explicit justification for the choice of survey methodology, while retaining some flexibility should this require modification in the light of particular site conditions at the time of fieldwork. The choice of survey methodology will be appropriately matched both with the archaeological and logistical demands of the project.

SCO Start-up and planning

Consideration of geophysical survey can be most crucial during the early stages of project planning. Indeed, in many programmes of archaeological evaluation the geophysical survey will be completed and acted upon, as a self-contained project, entirely within this phase. In the right circumstances such survey can provide information of great clarity on the extent and nature of archaeological deposits and features.

Most evaluations will be initiated with a desktop study followed by an assessment of all other extant documentary records, including aerial photographic coverage.

> Mark only correct answers

> ***Animation***

Such a study should also determine the following information relevant to geophysical survey:

- solid geology
- drift geology
- soil type
- current land use and surface conditions
- history of previous ground disturbance
- history of previous geophysical survey (if any)
- legal status of the site

SCO Project execution

Project execution includes fieldwork, assessment of potential, archive deposition, and dissemination.

> ***Animation***

As regards fieldwork, the following stages of geophysical survey fieldwork should be considered and planned for, where appropriate:

(Pilot (test or trial) survey: it may occasionally be necessary for a preliminary assessment to be made of a site's response to geophysical survey, particularly where large areas (>20ha) are concerned. Such preliminary information, based on expert assessment, can forestall the wasteful deployment of resources on inappropriate techniques and on sites where the use of geophysics is unlikely to be helpful. Any pilot survey should not usually take more than a day to achieve, and the results should be made available immediately for incorporation into the project design.

Full survey: once this justification is assured an agreed survey strategy can proceed. This may be full or partial coverage of the site at high or low levels of detail, using one or more techniques, depending on the strategy adopted.

It is particularly important at this time to establish a secure and agreed timetable in which the above stages of survey are correctly integrated with the other evaluation strategies. This should be sufficiently flexible to accommodate additional contingency survey, and costing should allow for this. Above all, the timetable should permit adequate time for the results of geophysical survey to be fully reported in order to inform subsequent project planning. Once the report has been made available, allowance should be made for the project team to communicate with the surveyors to discuss any outstanding matters, especially as these may relate to the archaeological interpretation of the geophysical data.

Good timetabling must be linked with full and informed cooperation between all parties. Particularly relevant to geophysical survey is that landowners and/or their agents and/or tenants have been informed and given their permissions for the survey to take place. Obtaining such permissions, as well as details of access and the resolving of any other local complications, should usually be the responsibility of the project manager rather than that of the surveyors.

SCO Data interpretation

Raw geophysical data can be obtained, processed and presented in a different way. However, the interpretation that follows generally requires a wider experience – encompassing an understanding of the site conditions and their history, the principles of archaeological geophysics, as well as the foibles of instruments and survey methodologies. A good knowledge of archaeology is of course important, as well as of geology and geomorphology. Ideally an interpreter will already have such experience, and will preferably have conducted and/or directed the fieldwork concerned personally (although it need not follow that the fieldworker is thereby automatically qualified in the subsequent interpretation of the data).

The factors that require consideration in arriving at an interpretation will vary from site to site, but should normally include at least the following (match the terms with proper columns):

> *Animation*

natural	artificial
solid geology	landscape history
drift geology	known/inferred archaeology
soil type	agricultural practices
soil magnetic susceptibility	modern interference
geomorphology	survey methodology
surface conditions	data treatment
topography	any other available data
seasonality	

Arriving at an interpretation that takes into account so many factors can be a finely balanced process and the outcome will be coloured by, and depend significantly upon, the experience of the interpreter. Above all it is crucial that any interpretation draws a clear line for the reader between demonstrable fact that is securely supported by the data, and less secure inference. Here, we would only warn against a tendency to see and attribute significance to every detail – in other words, to over-interpret. Minutely annotated plots with laborious textual referencing of every apparently significant anomaly stretch the credibility and wear down the patience of readers. Generally speaking, it is preferable to exercise as much objectivity and restraint as possible, and to err towards under-interpretation, resisting the embellishment of plots with wishful patterns and details.

Refinement of the interpretation of geophysical surveys is, to a significant degree, dependent upon the feedback of 'ground-truth' following the survey fieldwork. Wherever possible every effort should be made to encourage such feedback and its subsequent dissemination into the general pool of accumulated experience. To aid this process, curators can stipulate that trial trenching and excavation reports are copied to the geophysical contractor, that mitigation and publication briefs make allowance for the results of geophysical surveys, and that reporting includes the post-excavation comments of the geophysical contractor (if appropriate).

> SCO Exercise
> SCO Glossary

SCO References

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→ LU Aerial archaeology in preservation and management of archaeological heritage in Poland

Case study Aerial reconnaissance at Kraplewo
by Arkadiusz Klimowicz

SCO Introduction
Aerial archaeology is an integral part of modern archaeology and a constitutive element of current approach to protection of archaeological heritage (Kobylinski 2005: 22; Deuel 1984: 15). Its usefulness has been fully proved in numerous applications over the last decades. Polish archaeologists have been using different kinds of aerial prospection for more than eighty years. There are numerous examples of efficient application of aerial archaeology, both in academic and conservation practice.

SCO Foundations
Aerial archaeology is based upon possibility of conducting prospection of selected segments of landscape from the air and their subsequent photo recording. Its major objective comprises capturing relations between phenomena on the ground that can be detected from the air with archaeological sites (Kobylinski 2005:10). The aerial prospection has been very popular in Poland over the last years and resulted in discovery of numerous archaeological sites indicative of intense occupation in prehistory (Harding, Raczkowski 2010; Czerniak et al. 2003), as well as historical times (Dernoga et. al 2007). Hence, it proved usefulness of aerial prospection in recognizing archaeological resources. Accordingly, it became a significant method in formulating a doctrine of protection and management of archaeological heritage. An aerial reconnaissance at Kraplewo can serve as a good example of its effectiveness. Kraplewo is located c. 25 km south of Poznan at the edge of a big valley. The site was previously unknown and was only recognized during aerial reconnaissance. It revealed existence of Medieval stronghold dated to the 13th century.

SCO Methods
The aerial reconnaissance at Kraplewo revealed a pattern of crop marks due to soil disturbance caused by human activity in the past. Due to their differentiated color it proved possible to recognize lithological disturbances indicative of a circular ditch of c. 31 m in diameter in addition to numerous irregular pits.

Accordingly, subsequent recognition of spatial structure of the site and its size was revealed by crop-marks. Their detection from the air makes possible to reveal different structures as all kind of disturbances under the surface are manifested in different features visible on the surface. Consequently, any permanent changes in the surface morphology made by people reflect today's conditions of plan vegetation.

Aerial photographs of this archaeological site reveal two categories of marks. Within the ditch, the so-called positive crop-marks have been recorded. These were caused by organic organic content of the infill accumulated (naturally and intentionally) within the Medieval moat. These kind of places usually keep moisture for some time making crops bigger and ripping later. At the same time, the occupation of the top of the hill on which the site was located, was recognized thanks to the so-called negative crop-marks and related to soil erosion and denudation processes. The resulting unfavorable conditions due to a shallow soil cover were reveled in the form of poor quality crops and early riping.

A possibility of recording different crop-marks is caused by a range of factors, such as soil type, the year season, humidity balance, character and type of cultivation as well as time of the day in which the photo was taken. The successful outcome of the aerial reconnaissance at Kraplewo in 2008 was thanks to a combination of all these factors. The summer draught made possible to capture a significant differentiation of conditions affecting crop vegetation within a single field, which made possible to reveal a cone stronghold.

SCO Procedure
A light aircraft was used for the aerial reconnaissance at Kraplewo. The crop-marks were revealed on oblique photographs taken by digital camera from the height of 200-400 m. The next step involved a comparison of the photos with topographic maps. The GPS device was used making possible to record the flight details and places in which particular photos were taken. Geographical coordinates of these spots

Figure 1 Aerial photo of the site at Kraplewo
(copyright: W. Raczkowski)

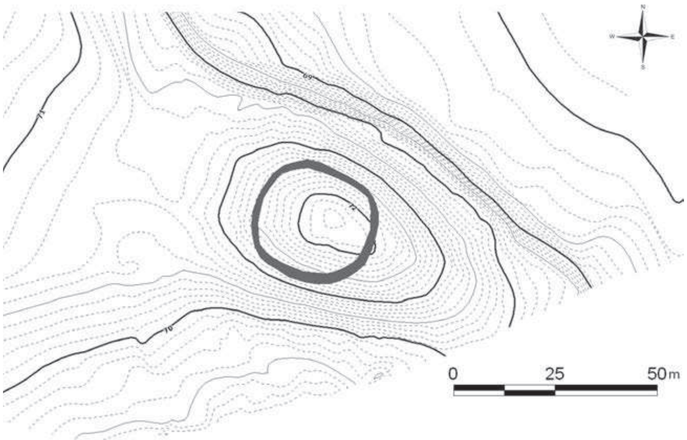

Figure 2 Plan of the 13th century moat within the current hypsography
(copyrights: Ł.Banaszek & L.Zuk)

made possible to precisely localize these sites. While taking subsequent pictures, a special attention was also paid to capture the so called reference points, namely distinct elements in the landscape making them easily identifiable on the map.

The photo material was later systematically interpreted. Its interpretation was aimed at identifying the details of observed crop-marks that are indicative of different archaeological features. Further procedure involved rectification of all oblique photos. This procedure makes possible to transform them into vertical photos. The rectified photos and their interpretation were later put on the map in the 1:25 000 scale, taking into consideration spatial structure of particular archaeological sites. This had a form of complete documentation to be used by the heritage offices in actions related to protection and management of these elements of archaeological heritage.

sco Results

The aerial reconnaissance at Kr plewo corroborated usefulness aerial photography as an efficient tool contributing to enlarging the information on archaeological resources. Its undisputable advantage is a possibility of precise recognition of the site size and range. In case of the Kr plewo site, details of the site reach resulted in administrative decisions ordering changes in the local spatial planning. Accordingly, the site verification by using aerial prospection techniques is particular significant in this case. It made possible to preserve the site by placing it in the register of sites protected by law.

sco Problems and limitations

Non-renewable character of archaeological heritage requires a systematic strategy of the heritage offices. Particularly important is management of archaeological resources, which involves a detailed recognition of archaeological resources in a given region. Furthermore, they also serve as a foundation of scientific projects.

Despite the fact that aerial prospection meets requirements of contemporary standards of protection of archaeological heritage (Raczkowski 2011), its potential has not been fully applied by the Polish heritage offices. Incorporation of aerial reconnaissance into the standard mode of recognizing and recording archaeological resources has only taken place in the mid 1990s (Kobylinski 2005: 80; Stepien 1998). This initial period was marked by attempts to standardize description and collection of photo materials using the standardized 'cards of area observation from the air' (Stepien 1998). These were only a simple addition to the already existing Archaeological Picture of Poland cards and were of no scientific and conservation value. This recording system was soon rejected due to its inefficiency.

According to the Polish conservation doctrine, aerial photographs do not provide any legal grounds for the protection of any given site or region (Raczkowski 2011). It can only be officially put into the register when archaeological material is found there. Accordingly, in the Kreplewo case, it was required to undertake additional studies, such as field survey, geophysical prospection, making possible to provide additional details of function and chronology of this site.

Taking into consideration contemporary standards of the scientific and conservation milieus, it is required to change procedures of storing, manipulating and efficient using of aerial photos to make them a valuable kind of documentation (Bronk-Zaborowska, Prinke, Zuk 2005). Consequently, such system would make a complete archive be easily available, easy to use and be applied for any research project.

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