Archaeological Geophysics

The purpose of this note is to seek to establish what geophysics is good and bad at and to give some information concerning the methods which are used. This is not intended to be comprehensive or universal and suggestions are welcomed from people who would like to add additional information concerning areas of their own experience.

Please contact the B A J R to do this – info@bajr.org

1. What is archaeological geophysics?

2. How useful is it?

3. How useful will it be for my site?

4. Magnetometry

5. Earth resistance (also known as resistivity)

6. Magnetic susceptibility

7. Ground Penetrating Radar

8. Further Reading

9. Useful Websites and resources

10. Appendix 1:
    What to expect from a geophysical report.

Guide created by
Abingdon Archaeological Geophysics
www.archaeologicalgeophysics.co.uk
1. What is archaeological geophysics?

This is the way in which people attempt to find underground features by using various, usually, electrical devices. The principal techniques used are magnetometry, resistivity, magnetic susceptibility, ground penetrating radar, electromagnetic techniques, metal detectors, seismic methods, sonar and micro gravity. Dowsing is also used by some people. Only some of the techniques will be mentioned in this note although if people have detailed experience of other methods please feel free to contact us.

Geophysics is only one of several techniques which are used to locate sites. The sequence would normally start with documentary and air photograph evidence, move on to geophysics and then end with trial trenching with each stage being influenced by the preceding one. It should normally not be used in isolation and, as the response of features to geophysical techniques varies, the absence of features in any geophysical survey does not necessarily mean that they do not in fact exist on the site itself.

2. How useful is it?

This depends greatly on the geology of the area for magnetometry and the dampness of the soil for resistivity. In the Evaluation of Archaeological Decision Making Processes and Sampling Strategies by Gill Hey and Mark Lacey, Oxford Archaeological Unit /Kent County Council 2001, they attempted to evaluate geophysics (principally magnetometry), desk based assessments, field walking and trial trenching. Whilst it is not possible to summarise the whole book in this paragraph they found that desk based assessment was reckoned to be 27 cent successful, field walking 30% geophysics 40% and trial trenching 60%.

This compares with the costs of those methods which were 4%, 12%, 32% and 49% of the cost of the evaluation phase respectively. Geophysics was found to be poor at locating post hole structures and pit alignments and ephemeral remains but it was good, (even better than trial trenching), at finding the layout of archaeological sites. The Iron Age and Roman periods appeared to have responded better to the magnetometry than Bronze Age and Neolithic ones. That study also included a single example of resistivity which successfully located the layout of a Roman villa and located an unknown hall adjoining it.
It should however be borne in mind that geophysics people are reluctant to have to tell their clients that they found nothing and will therefore tend to only recommend geophysics on sites which are likely to be suitable for the techniques they use.

By being non-intrusive it is possible to do the geophysics in such a manner as to lead to very little disturbance to the site which can then continue in agricultural use, unlike trial trenching which causes more disruption and can damage sites unless they are recognised early enough.

The usefulness of geophysics for investigating known sites was also not covered in that book. A detailed resistivity survey at 0.5 metre sample intervals could, for example, be expected to give a good degree of detail of a walled building but a survey at that sample interval would be too expensive to use in the hope of finding archaeological remains on, say, a motorway route evaluation.

3. How useful will it be for my site?

It is probably best to have a look at the English Heritage database of geophysical surveys on the internet. This may help to ascertain whether the soil conditions in your area are suitable for geophysical techniques and also avoid the embarrassment which could be caused by finding out that the site you are investigating has already been surveyed. Unfortunately a lot of surveys have been carried out in the past 4 years which do not appear to have been included on the database.

You could also have a sample surveyed of a known archaeological feature in the area in which you are interested. This should be on the same type of drift geology as your prospective site. This should help to establish which, if any, geophysical techniques can assist in detecting or defining your site. As a minimum magnetometry and resistivity should be tried although some surveyors may also be able to offer ground penetrating radar and magnetic susceptibility.

Everyone who is considering either commissioning or carrying out a geophysical survey should obtain a copy of the English Heritage Guidelines prepared by Andrew David. They may be 10 years old, and are due to be updated, but they are an invaluable start (and free).
4. Magnetometry

This is good for finding ditches, large pits gullies, kilns and ridge and furrow type crop marks. It is less good at finding small features such as postholes. Similarly it is not very often good at locating graves as these tend to the backfilled with the same material from which they were dug unlike ditches which tend to silt up more gradually and thus acquire fills with different magnetic properties to the surrounding soil.

The principle upon which magnetometry relies is that magnetically enhanced soil will cause a slight variation in the Earth's magnetic field over where it is located. This variation is often in the order of one or two units (nanoTesla) compared with the earths magnetic field which is typically 50,000 nanoTesla but this varies during a day. The apparatus used is therefore very sensitive and is affected by iron pipes and fences to the extent that a 2 metre high sheep wire fence can obscure data for 10 metres on either side although the less sensitive the equipment is the less it is affected.

Surveys carried out by this method can typically cover about 1-1.5 hectares of open land per machine per day although this will vary greatly depending upon the ground conditions. Open fields with short grass are fine but interruptions caused by field boundaries and trees can reduce progress to about 60%. Long grass, (over 100cms high), is a problem as it means that the sensors have to be carried higher off the ground and this adversely affects the data. This method relies upon the soil having an iron content which can have been enhanced by human activity in the past. It is therefore more successful in ironstone areas than in limestone ones although the soils which have developed on limestone are often capable of producing good results. In city centre areas there can often be so much interference caused by modern pipes and debris that this method is less useful, similarly the chippings used to make modern road surfaces are often of igneous origin and can obscure any features which lie underneath. Even on areas which are far from ideal for magnetometry it can still locate some features and spreads of iron debris, which often accompany settlement and this can guide further investigations.
Survey on poorly responsive site

Despite the alluvial clay cover various ditches can be seen

Survey on better geology

Here we have ridge and furrow with another field system at almost right angles to it and an enclosure in the top left grid. The top right looks quite promising as well. The line of white blobs in the bottom left is probably interference caused by metal pipe joints or similar.

Survey on good geology

Here the ditches and other features show more clearly so enabling any trenches to be small and appropriately located. The walls in the bottom right corner do not show up as well as the ditches do.
Equipment used for archaeological surveys should be able to detect variations of 0.1 nanoTesla and the surveys are normally carried out in lines 1 metre apart with 4 readings per metre along the line. Readings taken at 8 readings per metre can be carried out for little additional effort although this requires additional computing power to process the data. Additional information could be obtained by having lines at 0.5 metres apart although this would require the distance walked for each square being doubled.

The processing of data is important here as surveys can be carried out well in the field yet features not picked up at the processing stage. Reports should give the detail of the processing which has been carried out and this would typically be; clip to ±5 nanoTesla; despike and zero mean traverse. Other processes such as destagger and enhancing the data could also be carried out although there is always the risk that excessive processing will produce spurious artifacts which imply archaeological features which do not exist in reality. For magnetometry reports it is usual to have a trace plot in addition to the grayscale illustrations as the trace plot contains information which assists in identifying the nature of features. Programmes such as ArcheoSurveyor and Geoplot tend to be used for this although others such as Surfer are also available.
5. **Earth resistance** (also known as resistivity)

This is, in theory, the simplest method as it relies on detecting the electrical resistance of the soil. In practice this is a bit more complex as it has been found that if you just place two probes into the ground then the current between them will change as the ground around the terminals becomes polarised. Then if you then stick the probes into the same area again you get a different reading. This is caused by the contact between the soil and the probes changing each time as different surface areas of grains touch the surface of the probes. To overcome this various arrays of probes have been developed but these rely on the current being sent via one set of probes and read by another set. There are various arrays such as Wenner, Schlumberger, pole-pole and Twin. The most commonly used are twin and pole-pole which involves having a pair of remote probes at least 15 metres away from the area being surveyed (assuming 0.5 metres between the probes in the survey area). For twin the remote probes are spaced approx 0.5 metres apart and this is increased to over 15 metres for pole-pole.

Earth resistance is largely dependent upon the moisture content of the soil as a ditch will often have silts which retain moisture whilst the natural soil around may be more freely draining. Of course the opposite can happen as rubble filled ditches can be more freely drained than the surrounding soils. Similarly walls tend to be drier and give higher resistance values than the soil around them.

Various pieces of equipment are used which can give between one and four readings at a time. Usually these are by probes which are separated by 0.5 metres which can give a depth of reading of almost 1 metre depending upon soil conditions. A 1 metre separation between the probes in the survey area, (the mobile probes), can go even deeper. This method is good for finding walls but has the drawback of being far slower than magnetometry—about one third of the speed at best. The data often needs less processing than magnetometry data although high pass filtering can be useful to remove the effects of geology on a site, and de-spike used to remove the effect of the occasional poor reading caused by the probes hitting stones on the soil. The other main drawback of this method is that it is greatly influenced by the amount of moisture in the soil. In the summer soil conditions can be too dry to get good results and in the winter the opposite can be the case although very often something shows at most times of the year it is just that at optimum times the clarity of the features is far better.

For a resistivity survey one should expect to have a grayscale or colour image showing the site and for these edges of the individual blocks of readings to have been matched up as either the gap between the remote probes needs to be varied or software used to enable the blocks to be matched every time the location of the remote probes is changed.
By increasing the width between the probes in the survey area it is possible to locate features at different depths. A fairly common array is to take two half metre readings with a third reading between the outside probes of the three probe mobile frame which then takes a reading at 1 metre separation. This will give an indication of the earth resistance picture at a lower level. A development of this is pseudo-sections and tomography where a line of probes is set up and current passed between the probes in different combinations to give readings at different depths. Once a line of readings has been taken then the array is moved and a fresh line of readings taken and these are then merged.

Colour and grayscale illustrations of a barrow on chalk geology. 20m grids. Readings at 0.5m centres. 0.5m width between mobile probes. High resistance is dark/red – low is light/blue.

It located the barrow ditch and probably located some 1930s’ excavation trenches.

Parts of the high resistance inside the ditch may have more to do with modern animal burrows than being the upcast from the ditch. The blank lines are dummy readings logged where the survey area was obstructed by modern fences and vegetation.
6. Magnetic susceptibility

This, like magnetometry, relies on detecting iron particles in the soil which have been made more magnetic by burning which is usually by man. In addition to human action some bacteria contain small magnetic particles and these can also lead to increased readings. Whilst magnetometers are good at finding ditches and similar cut features, the magnetic susceptibility equipment, which looks a bit like a metal detector, detects shallow spreads of magnetically enhanced material and has an effective depth penetration of some 150 millimetres.

It works by the passing a current through the coil which magnetises the soil underneath it and then seeing how easily all the soil was able to be magnetically enhanced. Typically one would do a grid with readings every 10 metres which can lead to faster coverage than magnetometry. When the readings are plotted out areas can be identified which have higher readings and these can then indicate areas which could be investigated further.

This technique therefore can find deposits in the topsoil where archaeological features have been either ploughed out all are being brought up by the plough although worm action can also bring magnetically enhanced material to the surface. The effect of bacteria is shown by some fields producing higher readings than others and these are often old pasture lands which have recently been ploughed up and for some reason these tend to give higher readings.
7. Ground Penetrating Radar

This equipment relies on a very accurate clock which can see how long it takes for a radio wave to enter the ground and be reflected from a feature or layer within the ground and be received by the detector. Different wavelengths can be used with the result that this technique can see things if they are large at some depth and if they are small it can identify them at a shallower depth. The good things about this technique are that it can be used over hard surfaces such as tarmac and that it can give a vertical section through the deposits. These vertical sections can then be put together and sliced horizontally giving time slices which are far more understandable. The drawbacks are that a good amount of computing is required to make sense of the initial data as the sections, when they are first prepared, appear to contain lots of arches which are caused by reflections from a single point being received by the detector as it is moved over the ground surface. Migration software is therefore needed to take these hyperbola down to the points from which they originated. The other main disadvantage is that this technique does not like dampness in the soil as this quickly reduces the depth to which the radio waves can penetrate.

Coverage by this method is currently slower than by magnetometry or resistivity which is why it tends to primarily be used to see underneath hard surfaces and in some urban areas where other techniques cannot give the vertical get information which may be required, and where magnetometry and resistivity can be affected by iron pipes and electrical currents which lie within the soil. In Europe, as opposed to the UK, this method tends to be used on open sites where resistivity methods would be used in the UK.
8. Further Reading

1. David A. Geophysical survey in archaeological field evaluation, English Heritage 1995 *(The official guideline - really good but is due for updating soon)*


3. Gaffney C and Gater J. *Revealing the Buried Past* Tempus Stroud 2003 *(A good general book with the methods, field practice and case studies)*

4. Clark A. *Seeing Beneath the Soil* Batsford London 1990 *(Surprisingly good still despite its age gives the main methods and equipment)*

9. Useful Websites and resources

**Abingdon Archaeological Geophysics**
www.archaeologicalgeophysics.co.uk *(Gives details of resistivity and magnetometry, sample surveys and links to other useful sites)*

**Archaeological Prospection Resources** Department of Archaeological Sciences, University of Bradford
www.bradford.ac.uk/acad/archsci/subject/archpros/archp_nf.php List with resources relevant to Archaeological Prospection

**ArcheoSurveyor**: Specifically designed for the needs of our profession, ArcheoSurveyor is a complete package for downloading, assembling, enhancing and saving the geophysical data from a range of instruments
www.dwconsulting.nl/archeosurveyor.htm

**Geoscan Research** designs and manufactures geophysical instrumentation for both professional and amateur use.
www.geoscan-research.co.uk/

**Geophysical Survey Database** provides an on-line index of the archaeological geophysical surveys undertaken by the Archaeometry Branch of the Ancient Monuments Laboratory since 1972.
http://sdb2.eng-h.gov.uk/

**Geophysical Survey in Archaeological Field Evaluation 2nd Edition**
English Heritage 2008
http://www.helm.org.uk/server/show/nav.7740
Appendix 1: What to expect from a geophysical report.

The English Heritage guideline gives details of the content which they consider to be appropriate. This will not be repeated here but in general it has:-

1. The title page which includes who the parties were who required the report and carried out the survey and the date of the report
2. A summary page with an abstract of the findings
3. An introduction with an Ordnance Survey grid reference. This should enable the site to be located to within 1 metre and therefore any grid references will need to be in the order of S P 71326 50183. This should also contain a description and history of the site although this should not obscure the fact that this is the geophysical survey not an exercise in historical documentation. It should give details of the solid and drift geology and surface conditions and other factors which may have influenced the survey.
4. Next the methods are discussed where the reasons for the choice of method used are given. Hopefully this will not be in along the lines of “I only had this equipment therefore I decided that it was appropriate for every site”. The technical details are then given concerning the instrumentation used, the sampling intervals, and the processing carried out.
5. Following this is the description and interpretation of the results together with the conclusions which will relate to the degree of achievement of the original objectives and give any other factors which have arisen from the survey.
6. The usual acknowledgements, disclaimers, limitations and references
7. Appendices giving a location plan at a scale of a minimum of 1: 2500 and the plots of the data with a plot of the raw data and plots of the enhanced data at a scale of a minimum of 1: 1000. The data should be shown as trace plots as well as grey tone and there should be an interpretation diagram. The interpretation diagram will usually be defining high and low anomalies and indicating which ones can be caused by metal spikes and which by archaeological features. Often archaeological organisations then examine these reports and decide whether the circular anomaly is an Iron Age round house or small henge as this degree of interpretation is not often carried out by the geophysical organisation.
8. The final piece should say where the survey is to be deposited. This should be with the local Sites and Monuments Record as a minimum as they could then send it to the National Monuments Record (or whoever that organisation is nowadays). The Archaeology Data Service also can keep digital archives for a modest fee but these archives are designed to be available to the public so it may not be appropriate to send them confidential or sensitive data.

As surveys of this nature are often carried out as part of the Planning process there is a good likelihood that it will be read by Planning Officers and other parties who do not have expert archaeological or geophysical knowledge. The language used should therefore be designed to enable such persons to be able to make sense of the report. Similarly as reports are often photocopied as part of the Planning process it would help if the plots and interpretation plots could be in grayscale as well as colour.
Disclaimer
Whilst the contents of this document are put together to give a view of the current situation and the advantages and disadvantages of various methods this is a fast changing area and opinions will differ. Therefore no responsibility can be taken for any losses which made arise through following this advice.

Acknowledgements
I would like to thank the people who have agreed to their surveys being included here and those who have commented on earlier drafts.