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Application and Limitation of Geophysical Techniques in Archaeology

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Abstract: Archaeology is destructive. As a site is dug up it is systematically destroyed, hence each step of the dig must be painstakingly slow with careful documentation at each level. Geophysical probing on the other hand is rapid, non-destructive, and does not disturb the site. Geophysical methods have been used with increasing frequency in archaeology since 1946; aerial photography has been used since 1919. The geophysical methods that are most commonly used at present are electrical resistivity, magnetics, and ground-probing radar. Magnetic detectors, particularly when used in a gradient mode or with a continuously recording base station, are used at almost all sites where any geophysical methods are used. Portable, noncontacting electromagnetic soil-conductivity systems are also being increasingly used because of their very high rate of data acquisition. Less commonly used methods include self-potential (sometimes called spontaneous potential), microgravity, radiometric, thermal infrared imagery, and sonic or seismic techniques. Recent developments in image processing and graphic representation have contributed substantially to the archaeologist's ability to do “rescue archaeology,” that is, to carry out high-speed, nondestructive reconnaissance surveys for ancient human cultural evidence in advance of modern industrial development. Precise spatial positioning of architectural remains was impossible without additional investigation. Thus, the aim of applying geophysical survey methods was to ascertain the reliability of a ground plan based on old archaeological excavations and to produce a more detailed settlement reconstruction.

Key words: Geophysical Techniques, Archaeology, electrical resistivity, magnetic, and ground-probing radar, Application , limitation

INTRODUCTION

World War One brought the discovery that photographs behind enemy lines taken from airplanes could be of great value in warfare. Not longer after this, observers taking random photographs from the air over rural England noticed that traces of old Roman walls, forts and roads could be seen on aerial photographs but otherwise went unnoticed under cornfields and pastures when archaeologists wandered about

The country side on foot. Terrain photos from captive balloons had been made even earlier (1860) but it was only in the 1930's and 40's that archaeologists began to take advantage of photos from the air over archaeological sites.

Prior to the Second World War electronic methods began to be employed in earnest in searching hr oil and large mineral deposits beneath the surface of the earth. Because of the big economic payoff, successful discoveries made possible by even primitive geophysical methods were high enough that R&D budgets soon became generous. An explosion of knowledge in geology, earth science, geophysical and remote sensing followed. After World War 2 all the sophistication brought by war time research then also became available to private industry, producing a new,

Even bigger, boom in geophysical exploration. Historically, the scale of exploration required for oil and mineral exploration for most of these methods was very large (of the order of kilometers), while in contrast the scale of interest to an archaeologist is only centimeters or meters. As mentioned, the application of some of the above geophysical methods to archaeology began in earnest after World War II, but in contrast to the huge budgets available for petroleum and mineral exploration, archaeological budgets have almost always been minuscule. Usually the chief archaeologist at a site is a reputable and experienced professor whose modest salary is paid by his school so that he can teach university classes and do some seasonal field research on the side. The field work in archaeology has always depended mostly on student volunteers and assistants. Small amounts of financing are sometimes available from museums or grant institutions such as National Geographic

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Society, the National Science Foundation or the Smithsonian Institution. Usually digging at an archaeological site must be done by hand though occasionally massive amounts of overburden must be removed, or trenching done, with the help of a back-hoe or bulldozer. Cataloging, preserving artifacts (conservation), and publication of scientific papers occupies the off-season, but often funding levels for these important activities are also minimal.

It is more than a decade since the appearance of Technical Paper No. 9 (Gaffney et al 1991). The use of geophysical techniques in archaeological evaluation has

Increased tremendously during this time and this revision will update the professional archaeologist in light of recent work. The paper is still aimed at people writing briefs or commissioning a geophysical survey as part of an archaeological evaluation. At the outset,therefore, geophysical strategies will be discussed with particular respect to the location and delimitation ofsites. Emphasis will now be on the main geophysical techniques used in site investigation, indicating the limitations of the methods. The type of archaeological features that are likely to be detected will be discussed and the conditions which make a site suitable for survey will also be considered. Limiting factors such as geology, pedology, ground conditions and modern disturbances are also referred to.

It is not our intention to instruct people in how to carry out geophysical surveys or how to use the variety of instruments available. Field procedures will only be discussed insofar as they are relevant to the design of an archaeological project.

In view of this, we are of the opinion that geophysical work in archaeological assessments should only be carried out by specialist operators, with recognised geophysical experience and qualifications.

2. Strategies in Field Geophysics:

Geophysical techniques were first used to identify promising areas for excavation and to place excavations in a wider context. Today, areas requiring evaluation are often immense and the time scale short. Although the speed of survey has increased dramatically, it is still often necessary to adopt a sampling strategy. Fortunately these have been long practiced in archaeology and archaeologists are aware of their uses and limitations.

Large scale geophysical evaluation strategies have evolved considerably during the last decade.Strategies adopted for a small area of crop mark evidence for settlement will be different from those for a large development with the same evidence tucked into the corner of only one of many fields.

4. The Basis of Geophysical Methods:

Although an unusually large number of detection devices have been used for archaeological prospecting (see Wynn 1986 for a history), only a few have become Standard in evaluation projects.
Some were simply due to instrument stability; whilst others were inherent in the techniques. The following section will describe geophysical techniques most frequently used in archaeology. The basis for each and their potential for evaluation are discussed.

3.1 Electrical:

Electrical methods use the fact that although most rock forming minerals are insulators, electrical current can be carried through the earth by interstitial water held in the soil/rock structure. Resistivity, Self Potential and Induced Polarization can all be used, although only resistivity has become a standard technique.

The Electrical Conductivity Method:

The apparent electrical conductivity was measured with an instrument (*Geonics EM38*) in vertical dipole mode, where by the longer side was set in the direction of the profiles. In this configuration the sensitivity of the instrument is at its highest for depth, which is the same as the distance between the coils, that is, 1 m.

3.1.1 Resistivity:

This has the longest association with archaeological investigation (Aitken 1974) and is the most widely used electrical method. Its simple practicalities have also been borrowed from this source Resistivity relies on the relative inability of materials to conduct an electrical current. As resistivity is linked to moisture content, and therefore porosity, features such as wall foundations will give a relatively high resistivity response, while ditches and pits, which retain moisture,give a lower one.

The method involves injection of a small electrical current through the earth and measurement of subtle sub-surface variation in resistance over a given area.

Resistivity surveys can be carried out in one of two ways. Firstly, a constant spacing traverse, i.e. electrical profiling, measures lateral variations in resistivity and is most widely used for planning features. Vertical electrical soundings, i.e. electrical drilling, study horizontal or near horizontal interfaces (archaeological layers). Comparisons with theoretical curves enable the depth of such interfaces to be calculated. More recent surveys have highlighted this vertical component, using pseudo-sections or tomography. These surveys rely on the theory that as one expands the probes, data are recorded at a greater depth. Complex switching systems control long lines of electrodes and the resulting data Provides a vertical section through the ground. These lines can generate a 3D image of the subsurface.In recent years we have seen a number of advances in Resistance survey for archaeology.

3.2. Magnetic:

The basis for magnetic prospecting is weakly magnetized iron oxides in the soil. Depending on the state of iron oxides, the material will exhibit either a weak or a strong magnetization. Two phenomena relevant to magnetic anomalies are thermoremnance and magnetic susceptibility.Thermoremnance describes weakly magnetic materials that have been heated and thus acquired a permanent magnetization associated with the direction of the magnetic field within which they were allowed to cool.

For this to be possible the body in question must be heated above a specific value, known as the Curie Point (CP). This wipes the inherent magnetic orientation of the body clean, so on cooling the material acquires a new magnetic property specific to its relative position in the Earth's magnetic field. Archaeological features that have been through this mechanism include baked clay hearths, and kilns used for ceramic manufacture.

Importantly, whilst this creates a readily identifiable,even characteristic, signal, the same property makes describes weakly magnetic materials that have been heated and thus acquired a permanent magnetization associated with the direction of the magnetic field within which they were allowed to cool.For this to be possible the body in question must be heated above a specific value, known as the Curie Point (CP). This wipes the inherent magnetic orientation of the body clean, so on cooling the material acquires a new magnetic property specific to its relative position in the Earth's magnetic field. Archaeological features that have been through this mechanism include baked clay hearths, and kilns used for ceramic manufacture.

Importantly, whilst this creates a readily identifiable,even characteristic, signal, the same property makes magnetic results on some igneous geologies very difficult to interpret.

Magnetic Susceptibility is the key to coherent results from magnetic surveys. Moreover, not only can the difference in magnetic susceptibility between topsoil and sub soils be used in a predictive manner, but also the spatial variation of susceptibility enhancement throughout the topsoil itself indicates 'activity' in the archaeological context.

The theories of Le Borgne (1955; 1960) are the most frequently cited in the discussion of magnetic susceptibility. He suggested a simplified transition of
iron oxides as follows:

haematite > magnetite > maghaemite

This is achieved by conditions of reduction followed by oxidation. He proposed two mechanisms which produce these conversions: fermentation and burning.

The burning mechanism is fairly well understood and hinges upon the thermal alteration of weakly magnetic/antiferromagnetic iron oxides to more magnetic oxide forms. The fermentation pathway is both a subject of debate and an unhelpful misnomer.

This pathway explains the general tendency for top soils to have a higher magnetic susceptibility than sub soils,assuming a non-igneous parent. The mechanism is a product of biological-pedological systems and probably involves the interaction of microbia, soil organic matter and soil iron (Fassbinder *et al* 1990: Fassbinder and Stanjek 1993).Anthropogenic activity generally increases susceptibility and roduces detectable anomalies (Tite and Mullins 1971). Even in the absence of the heating mechanism of enhancement, detectable features can be produced, for example by the infilling of a ditch with relatively enhanced topsoil materials.

3.2.1. Magnetometry:

Although the changes in the magnetic field associated with archaeological features are usually weak, changes as small as 0.2 nanoTesla (nT) in an overall field strength of 48 000 nT, can be accurately detected using a dedicated instrument. Mapping the anomaly in a systematic manner will allow an estimate of the type of material beneath the ground. Anomalies that are of interest are the product of relative contrasts between the subsoil and magnetically enhanced topsoil.

In terms of archaeological features, one can imagine a ditch cut into subsoil. Silting or deliberate infilling of the ditch with magnetically enhanced topsoil or other materials will create a magnetic contrast which would produce a characteristic anomaly. The anomaly changes in shape depending on the interaction of the localized field with the earth's magnetic field. In Britain, a pit or ditch containing enhanced deposits will produce an anomaly with a positive peak to the south and a corresponding negative to the north. The displacement will be no more than 0.25m, better than the precision on the sampling interval.

3.2.2. Magnetic Susceptibility:

Measurement of magnetic susceptibility can be carried out by two methods. Firstly, there is the field coil, which allows rapid measurement of large areas. One Disadvantage is poor penetration (c 10cm) of the signal, although this in part can be circumvented by judicious use of field sensors or use of a field probe inserted into augured holes. Another is that it gives a bulk measurement of soil, stones, air and water. The second technique is the laboratory determination of susceptibility for a standard volume or mass. This gives a truer measurement as the samples are dried and the coarse fraction (all materials, such as stones and foreign bodies, over 2mm in diameter) is excluded by sieving.

The downside is the time it takes to prepare samples. However, if soil physical and chemical property analyses (such as trace element analysis, total P, particle size analysis or loss-on-ignition) are to be undertaken, laboratory analysis becomes feasible.

3.3. the Ground Penetrating Radar Method (GPR):

The GPR method is based on the transmitting of high frequency electromagnetic waves via a transmitting aerial, or transmitter, directed at the ground and a recording of the times and amplitudes of the reflecting waves registered by the receiving aerial, or receiver. Once the electromagnetic wave reaches the Electromagnetic limit, part of the energy reflects towards the surface and is registered by the receiver, while another part continues to disseminate through the media to the next electromagnetic limit.

Measurements were carried out using the classic reflection measuring technique, where there is a short distance between the transmitter and the receiver. The resolution is mostly dependent upon the wavelength. The wavelength of electromagnetic waves from a 200 MHz antenna, as was used in the GPR investigations at Dolge njive, measures 1.5 m in the air. In materials with a relative dielectric constant of 15, this wavelength decreases to 0.52 m, and further down to 0.4 m with a dielectric of 25, etc. (CONYERS,GOODMAN 1997). The suitability of using an antenna with a central frequency of 200 MHz and twice as large a wavelength from a 400 MHz antenna, which is also most recommended for archaeological purposes,is best confirmed by the archaeological evidence corresponding to the results of the GPR research (MUŠIČ,HORVAT 2007).

GPR sounding was used to determine the depth and height of preservation and the spatial relationship of the architectural elements in areas of the settlement, wherever the results from geo electric mapping deemed it advantageous to check .

The primary advantage of GPR is its ability, when more than one section is investigated, to provide a three dimensional view of a buried site.

Whilst initially the main advantage of GPR was viewing a vertical section through the ground, experience has shown that it is far easier to view data as a map.

3.4. Other Detection Techniques:

These techniques are of secondary interest in evaluation work.

3.4.1. Electromagnetic:

Electromagnetic methods make use of the response of the ground to the propagation of electromagnetic (EM) waves. The most important aspect of the modern EM systems, such as the Geonics EM38, is the ability to provide a measure of both the magnetic susceptibility and the electrical component of the soil. The latest version allows both values to be measured simultaneously. Some instruments take measurements at different frequencies, but their potential in archaeological evaluation is still to be proved. One of the reasons EM instruments are used in drier climates is that they do not require contact with the ground and that they perform better than electrical resistance techniques on sites with a dry surface. This means they can be used in summer or over tarmac surfaces.

In other words, EM systems often work best in survey areas where resistivity techniques often fail. EM surveys can be used for mapping the remnants of mounds, tracing in-filled fortifications, locating buried stone structures or rubble, pits, and metallic artifacts.

3.4.2. Metal Detectors:

Metal detectors are one of the most frequently used tools in searching for artifacts, rarely the main aim of an archaeological evaluation. However, when used within a structured design for an evaluation there are clear benefits.

3.4.3. Seismic:

In seismic surveys, artificially generated seismic waves propagate through the subsurface. The travel times of the waves, which return to the surface by reflection and refraction at boundaries with differing reflection coefficients, are recorded. Travel times are converted into depth values giving a vertical section.

While seismic *reflection* has been used for the detection of tombs, it has several limitations. In most cases the soil layer is thin and may be beyond the resolution of the method. Interpretation can be extremely difficult when studying boundaries of complex geometry. Seismic *refraction* surveys are better suited to archaeological prospecting as they can give detailed information about a small area, and the data collection and processing are relatively simple. For examples of such a survey, see Goulty and Hudson (1994) and Ovenden (1994). An important consideration is that this technique is best suited to conductive soils. As a result it may be considered as an alternative to GPR, which does not perform well in wet or saturated ground.

3.4.4. Gravity:

A mass of material, or a cavity, will have a different density to that of the surrounding area, creating a density contrast which will locally distort the gravitational field, giving rise to a gravity anomaly. The survey method is time consuming and involves lengthy processing of data. Although not widely used in archaeology, some case studies have been reported (see Linford 1998).

3.4.5. Other Techniques:

The Self Potential (SP) method, also known as Spontaneous Polarizations, is based on surface measurement of natural potential differences resulting from electrochemical reactions in the subsurface. The field procedure is relatively simple, involving two nonpolarising electrodes connected via high impedance.

Millie volt meter. In theory, this method can detect corroding metallic artifacts, building foundations, pits and underground chambers. However, it has not been used extensively and its best applications remain unclear.

The Induced Polarization (IP) method is similar to resistivity and has comparable applications as it makes use of the passage of electrical current through the pore Fluids by means of ionic conduction. Induced polarization is measured by studying the variation of resistivity with the frequency of the transmitted current, with the earth acting as a capacitor. This has been tested on archaeological sites with some success, although research is required. It can detect metallic material (particularly disseminated material as the technique is dependent on surface area), in-filled ditches, and variations in the topsoil, particularly in the Clay content.

Buried features can create temperature variations at the earth surface that may be measured either using airborne detectors or ground probes. This so-called thermal detection is a continuing area of research, although the data are, at present, slow to collect at ground level, and may be difficult to interpret (Bellerby *et al 1992*).Dowsing has long been practiced in archaeology. Unfortunately the scientific principles are not understood (see van Leusen 1998). As such, the technique should not be used for evaluation purposes. In summary, it is suggested that there are only four techniques of proven reliability required for evaluation work on shallow sites. That is resistivity, magnetometry,magnetic susceptibility and GPR. By highlighting these four techniques we do not dismiss the others. Their potential has been noted and further research may allow them to be used as evaluation tools. To our knowledge,SP, IP, Thermal Detection or Dowsing have not been used in archaeological evaluations. 4. Types of archaeological Feature likely to be located using eophysical techniques

4.1. Fluxgate Gradiometer:

These are the most widely used geophysical instruments in evaluations. Even under ideal survey conditions, however, it is unlikely that features of archaeological interest will be identified at a depth greater than one meter. Its speed means large areas are covered quickly, and anomalies are reasonably easy to interpret. Under *normal* survey conditions a gradiometer survey is likely to locate:

ditches (>0.5m diameter),pits (>0.5m),pottery and tile kilns hearths and ovens ferrous debris, including some slags briquetage, pottery wasters, bricks and tile
burnt material, fired stones (eg burnt mounds)palaeochannels and other fluvial/geomorphological features .Under *very favorable* conditions it is also possible that the following features may be located:

larger postholes, slots and gulleys,walls.
Occasionally walls are detected as negative anomalies, but this is usually because they are buried in highly enhanced magnetic soils (see Gaffney *et al* 2000).

Occasionally, burials and ferrous grave goods may be detected, though these are generally difficult targets. While gradiometers can locate ferrous artifacts, nonferrous metals such as gold, silver, copper alloys, tin, and lead will not be detected.

4.2. Magnetic Susceptibility:

Sampling *Coarse* sampling intervals, say every 5, 10 or 20m may detect:

- Areas of archaeological activity
- Occupation and 'industrial' working areas
- Former fields in the form of areas of differing
- Susceptibility which appear to respect former field Boundaries.
- *Fine* sampling intervals; say every 1 or 2m may allow:

Some feature identification.

4.3. Resistance Survey:

Unlike gradiometers, resistance instruments measure moisture content, a factor which is naturally severely affected by localized weather conditions and, to a lesser degree, pedological variation. The technique's depth limit is dependent upon the probe arrangement. In the walls and rubble spreads made surfaces such as yards metalled roads and track ways stone coffins or cists (these are difficult targets)Features *normally* identified as *low* resistance anomalies include :-

large pits and slots (>0.5m)ditches ,very occasionally graves, drains and gulley's

4.4. GPR Survey:

GPR relies on dielectric contrast between differing materials. Under suitable conditions the following features may be identified (Conyers and Goodman 1997): refilled pits and ditches ,voids e.g. chambers, tunnels, buried paths and roadways
Walls, floors and rubble spreads, stone coffins, soil/bedrock interfaces.

On sites with a high moisture content or when investigating deeper features a lower frequency antenna is needed.

This will reduce the near surface resolution, in itself advantageous as it may reduce the 'clutter' produced by modern near- surface debris.

5. Complicating Factors Encountered in Surveying:

5.1. Magnetic Survey:

5.1.1. Field Factors:

• Wire Fencing:

As a rule of thumb, data must be collected at least 1 metre away for each strand of wire in a fence

• Overhead Power Cables:

These can produce massive magnetic anomalies that may restrict the usefulness of magnetic prospecting,sometimes up to several metres on either side.

• Pylons:

Pylons are problematic due to their large mass of ferrous material. In general 20 to 30 metres is the closest the operator can approach without spurious effects.

• Radio / Cell net / High Frequency Transmitters:

The effects are difficult to predict, as the response is dependent on the frequencies at which they operate.

• Electrified Railways / Overhead Cables:

The ferrous content is the overriding factor in determining whether the instruments will be affected. Passing trains will produce very large magnetic fields, which will cause temporary saturation of the gradiometer.

• ***Vehicles:***

A stationary vehicle can be detected by the gradiometer 20 - 40 meters away. The amount of disturbance is dependent upon the ferrous material in the vehicle.

• ***Buildings:***

Modern buildings normally contain fired brick, magnetic stone, steel reinforced concrete and corrugated iron. All of these result in magnetic fields that are likely to swamp anomalies of archaeological interest. Mobile homes and caravans, including site offices, present similar problems.

• ***Pipelines:***

Buried ferrous pipelines will have a marked effect upon the local magnetic field. Some of the utilities' larger pipelines will preclude effective use of a magnetometer up to 20 metres either side.

5.1.2. Ground Conditions:

• ***Modern Dumping:***

Modern material, for example lumps of concrete and clinker in plough soil, along with the artificial build-up of ground surfaces (e.g. embankments, consolidation and landscaping), all pose interpretational problems.

• ***Trees, Bushes and Shrubs:***

These are tolerable as long as the operator can walk in straight lines between them - dense vegetation will reduce survey work to a detail no greater than scanning.

• ***Crops, Undergrowth and Flowerbeds:***

Apart from crop damage, a major consideration is whether the gradiometer can be kept in a vertical axis without brushing against vegetation.

• ***Ploughed Fields:***

Wet, heavy soils will make work extremely difficult and can affect the quality of recorded data. Potato fields and deep ploughed areas should be avoided as they will often produce topographic effects, which can easily mask anomalies of archaeological interest. Similarly, tractor ruts can result in spurious anomalies.

• ***Ridge and Furrow:***

If surviving as earthworks visible on the ground, it is probable that the gradiometer will not record any major magnetic changes (unless preservation is so good that a topographic effect is produced).

5.1.3. Geology:

In general, the overriding factor is that there should be a measurable contrast in magnetic susceptibility between the topsoil and the subsoil/bedrock.

Sands and gravels can be particularly complex and their results can be highly variable, particularly where affected by a high water table. Some soils contain bands of magnetic sands and gravels that produce anomalies similar in character and strength to archaeological anomalies. In deep, undifferentiated coarse soils the change in magnetic susceptibility between the feature fill and the surrounding soil is small, resulting in very weak anomalies.

5.2. Resistance Survey:

5.2.1. Field Factors:

• ***Moisture Content:***

This is complex, as there are optimum times of year for surveying dependent upon the type of feature and soil porosity. However, in a developer-funded situation a decision has to be made as to whether the technique is suitable. As a general rule, extremes of weather are not necessarily the best conditions for resistivity survey, eg a ditch may retain moisture during drought and thus be detectable, but a wall showing as a parchmark may not produce an identifiable anomaly compared with the dry soil surrounding it.

• ***Buried Cables and Electric Currents:***

Modern instruments have sophisticated circuitry which can compensate for many of these effects, which tend to occur in urban or semi-urban contexts. Electrical noise is filtered out but this requires a slightly increased survey time.

5.2.2. Ground Conditions:

• Ploughed Fields / Parched Ground:

Both scenarios not only change the moisture content at the surface but also produce probe contact problems.Modern instruments can circumvent these to some extent, however, under extreme conditions survey may not be possible.

Living plants can create their own anomalies by distorting the moisture content in their immediate environs. Bushes invariably reduce the area available to survey.

• Differential Thawing of Ice and Snow:

Work can be carried out in snow or ice but allowance must be made at times of thawing.

• Areas of Waterlogging:

Puddles do not usually present problems although waterlogged land should usually be avoided. Torrential rain may cause some instruments to behave erratically. Sharp downpours on long dry grass may increase noise levels.

5.2.3. Geology / Pedology:

In general, problems only arise where the parent geology is close to the ground surface. Two significant factors are, firstly, conductive soils such as clays allow greater depth penetration of the electrical current giving a greater effective search depth. Secondly, in some environments, such as alluvial contexts or sandy soils, there is a marked spatial variation in soil texture.

This causes a natural variation in moisture content which can give anomalies of an archaeological appearance.

5.3. Magnetic Susceptibility:

5.3.1. Field Conditions:

Localized ferrous objects or magnetic debris will result in anomalous responses.

***5.3.2. Ground Conditions Magnetic Susceptibility*:**

Surveys are best carried out on areas stripped of topsoil, or with little or no vegetation. Ploughed fields, unless the ground has been harrowed, and vegetation covered ground, both present ‘contact 'problems for field coils.

5.4. Ground Penetrating Radar:

5.4.1. Field Conditions:

Cellnet transmitters, electricity cables etc, can all introduce noise into the GPR data. In a few cases this may render the technique unsuitable, but for the
majority of sites the data can be filtered to reduce these effects without degrading the data.

5.4.2. Ground Conditions:

• Vegetation and Surface Debris:

GPR requires a good contact between the ground surface and antenna. Tall/dense vegetation and surface debris will prevent this, introducing noise into the data.

• Tarmac, Hardstanding and Concrete:

GPR is one of the few techniques suitable for geophysical investigations on such sites and the level surface allows good contact between antenna and ground surface. However, areas of reinforced concrete are not suitable. Although the technique will accurately locate the steel reinforcements, very little information will be retrieved from any depth.

• Mixed Ground Cover:

Problems can be encountered where survey areas cover mixed ground, for example lawn and paths. The wide difference in surface response and signal attenuation results in marked variation from one to the other, which will limit the effectiveness of time-slicing the data.

5.4.3. Geology / Pedology:

Careful consideration has to be given to the depth of the expected archaeological features and the nature of the soils. Clayey soils will dramatically attenuate the signal,thereby greatly reducing the effective depth of investigation. While lower frequency antennae can be used to enable greater penetration of the signal, this will be at the expense of near surface and lateral resolution.

5. Advantage of Geophysical Methods:

- Archaeology is destructive. As a site is dug up it is systematically destroyed, hence each step of the dig must be painstakingly slow with careful documentation at each level. Geophysical probing on the other hand is rapid, non-destructive, and does not disturb the site.
- Not all archaeological sites *can* be excavated. Examples would be historic buildings, churches, mosques, the pyramids, parks, and areas which underlie modern urban development. Again, geophysical methods are non- destructive and very rapidly employed, hence often cost effective in the long run. In some cases these methods may be all that the archaeologist is able to use at some sites.
- Archaeologists can be greatly helped in setting his digging priorities if geophysical methods can be used ahead of time. Geophysical surveying can in many cases reveal artifact-laden vs. barren ground, and disclose important underground features: buried walls, voids, tunnels, ancient streets, etc.
- Many decades may be required to explore a given site, such as a tell. In fact total excavation of a site may be impractical. Geophysical survey work at a given sites can usually be done in a few days or weeks of effort, the results of which are useful for many years of subsequent excavation work.
- Salvage archaeology has become important as urban sites encroach on archaeological sites in many parts of the world. Thanks to modern legislation, substantial funding for archaeological research prior to the clearing of an area and construction of new buildings may be available. In many such cases, however, the time available for the archaeological effort may be very limited. Geophysical methods may be of great value as the site will often be totally destroyed by the new construction.
- The greatest advantage of these and other geophysical methods is that they are non-invasive. All these procedures can be done on a site before any excavation takes place. And they can usually be completed in a relatively short time. Geophysical methods can aid the archaeologist to develop a plan for excavation by leading him to the highest concentrations of artifacts.

6. Conclusion:

The aim of this paper is to combine the almost universal fascination we share for our past with the comparatively recent, in archaeological terms, application of geophysical prospection methods. For their success, each of these methods relies upon a physical contrast to exist between the buried archaeological feature and the properties of the surrounding subsoil. Understanding the archaeological origin of such physical contrasts, in terms of density, thermal conductivity, electrical resistance, magnetic or dielectric properties, remains fundamental to an appreciation of the discipline. This paper provides a broad introduction to the subject area acknowledging the historical development of the discipline and discusses each of the major techniques in turn: earth resistance, magnetic and electromagnetic methods (including ground penetrating radar), together with an appreciation of more esoteric approaches, such as the use of micro-gravity survey to detect buried chambers and voids. The physical principles and field instrumentation involved for the acquisition of data with each method are considered and fully illustrated with case histories of results from the English Heritage archives.

Traditionally, throughout the 1970s and early 1980s, geophysical techniques were used to create a ‘context' for the results of excavations. However, as the needs of Archaeologists have changed, so has the role for geophysical techniques? Many surveys are now undertaken to identify the most promising area to concentrate scarce resources. Some planning authorities have taken this concept a stage further: increasingly the object of a geophysical survey is not to establish where

The limits of the site are, or where best to excavate, but to answer the question ‘is there any reason to excavate within this threatened area?’

Clearly there are problems with this approach on areas where there are limiting factors (see above). In these cases, the quality of any geophysical data may be open to question, and to dismiss an area because it is devoid of geophysical anomalies may well be erroneous.

However, there can be no doubt about the overall contribution of geophysics to site evaluation. Unlike gradiometers, resistance instruments measure moisture content, a factor which is naturally severely affected by localized weather conditions and, to a lesser degree, pedological variation.

Types of archaeological Feature	method
Fluxgate Gradiometer	ditches (>0.5m diameter),pits (>0.5m),pottery and tile kilns hearths and ovens. ferrous debris, including some slogs briquetage, pottery wasters, bricks and tile burnt material, fired stones (e.g. burnt mounds)palaeochannels and other fluvial/geomorphologic features Under very favorable conditions it is also possible that the following features may be located: larger postholes, slots and gulleys,walls
Magnetic Susceptibility	areas of archaeological activityoccupation and 'industrial' working areas former fields in the form of areas of differing susceptibility which appear to respect former field Boundaries. Fine sampling intervals, say every 1 or 2m may allow: some feature identification
Resistance Survey	large pits and slots (>0.5m)ditches ,very occasionally graves, drains and gulley
GPR Survey	refilled pits and ditches ,voids e.g. chambers, tunnels, buried paths and roadways walls, floors and rubble spreads ,stone coffins, soil/bedrock interfaces

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