Investigating archaeological forms beneath the soil

Fieldwalking and aerial photography (discussed in other articles on this website) are methods of examining the surface of a landscape at large for signs of human activity. Field walking finds, for example, can give some impression of what remains may be present below the ground. Bricks and tiles hint at the presence of buildings while bones and pottery can suggest middens or pits. Increasingly, non-intrusive geophysical techniques are being used to provide mapping of sub-surface features over relatively large areas.

What geophysical techniques are used in archaeology?

Geophysical techniques were originally borrowed from the world of geology but now they have been refined for archaeological use. While many geophysical techniques have been developed, three are principally employed in archaeology: electrical resistivity, magnetometry and ground-penetrating radar (GPR).

How do the techniques work?

Useful results come from contrasts between archaeological features and natural background levels. In other words, if archaeological deposits or features possess physical properties different from the surrounding soil matrix, differences may be measured between them and the natural background. This may be in terms of their magnetic properties or resistances to an electric current or their ability to reflect radar energy. A buried brick wall foundation, for example, will probably be more magnetic, more resistant to an electrical current and better reflect radar energy than the surrounding earth.

(a) Electrical resistance. Basically this is measured by inserting electrodes into the ground, putting a voltage across them, measuring the resultant current and calculating the resistance (in ohms) between them by means of the equation R (resistance) = V/I (voltage divided by the current). Variations in electrical resistance are almost entirely governed by the amount of moisture in the soil or archaeological feature. Well-drained materials, such as sands and gravels, give rise to relatively high resistance whereas moisture-retaining material, such as clays and silts, give rise to lower resistance.

Under normal conditions (neither extremely wet or dry), resistance instruments are very well-suited for the detection of high resistivity (low moisture) features, such as walls, roads or rubble, or low resistivity (high moisture) features, such as ditches or pits, which contrast with the surrounding soil.


Figure 1. TR/CIA resistivity equipment

The twin probe array is the configuration most used in archaeological geophysics. It employs a pair of mobile probes (usually mounted 0.5m apart in a frame, as shown in the photograph here) connected by a 50m cable to a pair of remote probes. The mobile probe separation governs the approximate depth at which features are measured, for a 0.5m probe assembly depths of up to 1m may be read. A meter or digital data logger attached to the frame records the resistance data. Automated systems automatically record the result when a satisfactory contact with the ground is achieved.

In use, a survey grid is set up, usually based on 20 (or 30m) squares, as shown in Figure 2 below.

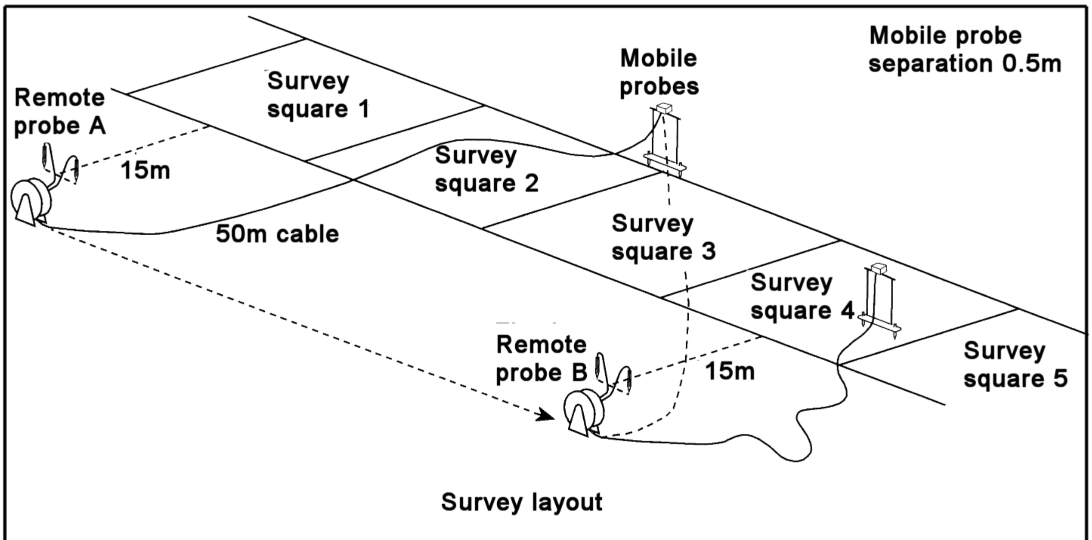

Figure 2. Layout of a typical resistivity survey grid, also showing the movement of the remote probes required to extend the survey area.

To measure squares 1 and 2 the remote probes are placed at position A, at least 15m from the nearest edge of the survey square – this is 30 times the probe separation, here shown as 0.5m. To measure squares 3 and 4 the restricted 50m cable length means the remote probes have to be moved to position B.

The mobile probes are left at the edge of square 2, having noted the resistance reading, and the remote probes are repositioned. Their separation is adjusted to give the same resistance reading as that for the edge of square 2. With the new position, squares 3 and 4 are measured. To measure square 5 and so on, the remote probes have to be repositioned each time further squares are measured. Measurements are taken at 0.5m (for more detail) or 1m (most commonly) intervals along each traverse, either in a linear or, more commonly, zigzag fashion (as discussed in the Fieldwalking article). The need to insert the mobile probes into the ground at each measurement makes this a slow technique to carry out.

After recording and processing the data, the results are often displayed as greyscale plots like the example shown here in Figure 3 (taken from English Heritage, 2006, page 3). This shows the walls of a number of Roman buildings on a villa estate at Dunkirt Barn in Hampshire. Not only do the main walls show clearly but the internal walls marking out rooms within the buildings are also visible. In this case the resistivity information was more informative than the magnetometry information gathered at the same time.

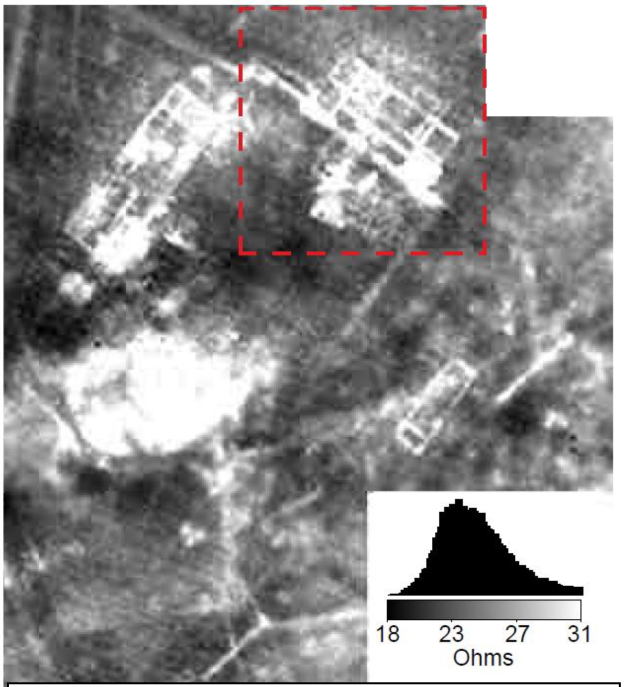

Figure 3. Resistivity survey results for the Dunkirt Barn Roman villa site in Hampshire (© English Heritage).

(b) Magnetometry. Magnetometers measure the magnetic field strength at any particular location on the surface of the earth. This field has two components: the earth's magnetic field at that point (this has a uniform value, typically around 50,000 nT or nano Tesla, with zero gradient over the whole site) plus any local contribution from geology or archaeological features (the latter values are typically only 1 – 2 nT). These local features add to the earth's field at that exact location and so the field gradient is no longer zero. To measure field differences as small as 0.1 nT requires a very sensitive magnetometer and this sensitivity requirement gives rise to certain problems – for example, iron is very magnetic and so a wire fence (or buried iron pipes or cables) can obscure the presence of more subtle features for several metres either side of the fence. Magnetometry does not work so well, therefore, in urban situations where buried ironwork is common.

How do archaeological features acquire a magnetic field? It relies on the presence of iron or iron oxides in the soil or artefact. Pottery, bricks and tiles or fire-heated soils such as hearths which have been heated above 575 – 675 ^{o}C acquire a permanent magnetic field on cooling. Igneous rock is also more magnetic than most soils so artefacts or building stone made of igneous rock will also have a high field - but this also means that magnetometry will not work well where the local geology is predominantly igneous. Pits and ditches, where the infill soil is different to the natural surrounding soil, may be more or less magnetic than the bulk soil and produce positive or negative responses.

There are three types of magnetometer detectors: proton, alkali vapour and fluxgate. Of these, the fluxgate detector is the cheapest, basically consisting of a metal rod surrounded by a copper coil. An external magnetic field magnetises the rod, causing a current to flow which is then measured. This type is most used in non-commercial or university archaeology. However, they are direction and temperature sensitive so they are normally used in the gradiometer configuration, as shown in Figure 4.

Figure 4. Geoscan FM256 gradiometer system

In this Geoscan system one detector is placed 0.5m (some systems can use a 1.0m separation) vertically above a lower detector and the difference in response between the two is equal to the magnetic gradient – it does not equal the total field. As any changes in the earth's field affect both sensors, those changes are effectively eliminated by this technique. Drift can still occur (especially due to temperature changes) and drift correction must be carried out at a fixed point, usually between grid squares. Assume the ambient magnetic field is 50,000 nT and that a pit 1m below the bottom sensor causes a local increase of 1 nT. The top sensor records a value of 0.3 nT so that the gradient is:

$$50{,}001 - 50{,}000.3\ \text{nT} = 0{,}7\ \text{nT}$$

A magnetometer survey uses a survey grid like that employed for resistivity measurements or field walking. However, because there are no probes to insert in the ground, the operator carries out the survey by walking without pause and it is much quicker to carry out than a resistivity survey. Modern instruments can take readings at timed intervals, usually marked by a beeping sound, so the operator has to walk at a rate sufficient to cover a traverse within the time set. The overall time depends on the ground conditions; for example short grass is fine but grass over 100cm tall can create difficulties. Similarly the presence of iron fences and trees may give rise to problems.

As with resistivity measurements, the data must be downloaded and processed. Magnetometry results may require more processing than resistivity ones. A typical result indicating various buried features is shown below in Figure 5. This example is from the estate area immediately behind the formal gardens at Wimpole Hall. The interpretation, confirmed by the subsequent excavation is as follows: the circular feature is the brick wall surrounding the fountain. The large signal in the centre is given by a metal grill subsequently built into the demolished fountain and the various parallel features are due to a number of brick-built

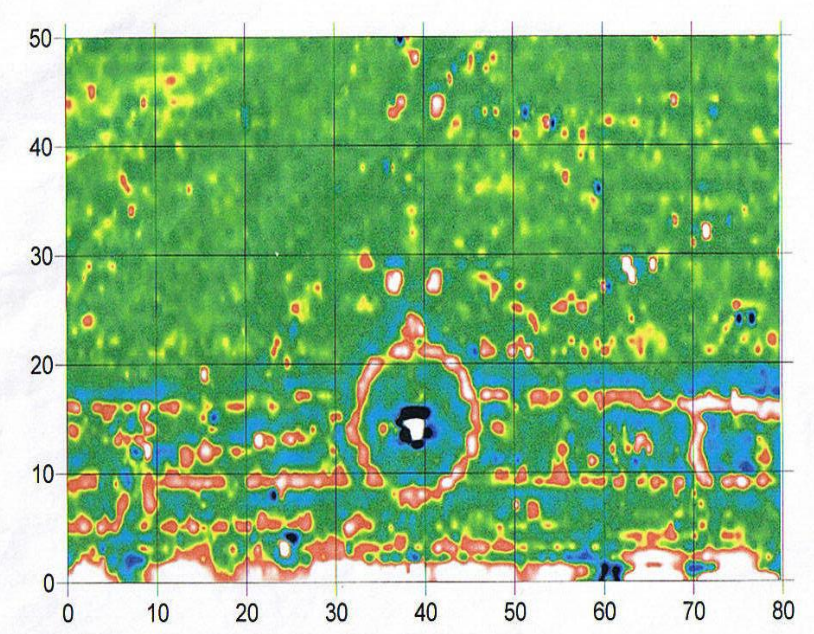

Figure 5. Magnetometry results showing the 18th C fountain and surrounding features at Wimpole Hall (courtesy of Peter Morris)

culverts and brick-filled drains

(c) Ground penetrating radar. Ground penetrating radar (or GPR) is one of the most complex of the geophysical techniques in terms of setting it up and processing/ interpreting the data. It is also one of the most expensive and is, therefore, normally only used by specialist commercial organisations.

The basic instrumentation consists of a transmitting antenna, which sends VHF electromagnetic pulses directed into the ground, and a receiving antenna, which picks up any reflected signals from sub-surface features. The two antennae are usually mounted as close to the ground as possible, usually in a cart together with a power supply, controller and a data logger (as shown in the Figure 6 photograph of a GSSI-manufactured system).

Figure 6. A GSSI GPR system mounted on a four wheeled cart.

A GPR system measures the travel time (in nanoseconds) for a radar wave to travel from the transmitter, be reflected at an interface and for the return to reach the receiver. It also measures the amplitude of the reflected wave (in decibels). Reflections are recorded continuously and for one particular horizontal point there may be hundreds or even thousands of measurements. In this way a two-dimensional distance vs. calculated depth profile for each transect can be calculated and displayed. By combining multiple pieces of transect information into a 3D display and then slicing it horizontally, a map of the surveyed area at various depths can be calculated. This is probably the most useful form for archaeological use and an example is shown in Figure 7. This is the GPR survey, using a 450MHz antenna, of the same Roman villa site at Dunkirt Barn shown in Figure 3 (taken from English Heritage, 2006, page 4). Down to ~ 0.3m the cloud of reflections represent plough damaged building remains (mostly flint nodules and rammed chalk). Beyond a depth of ~ 0.5m the archaeological remains become clearly visible and the survey displays a wealth of information.

The depth and spatial resolution capability for a particular GPR system depends on various factors but a key one is the frequency of the radar transmission antenna.

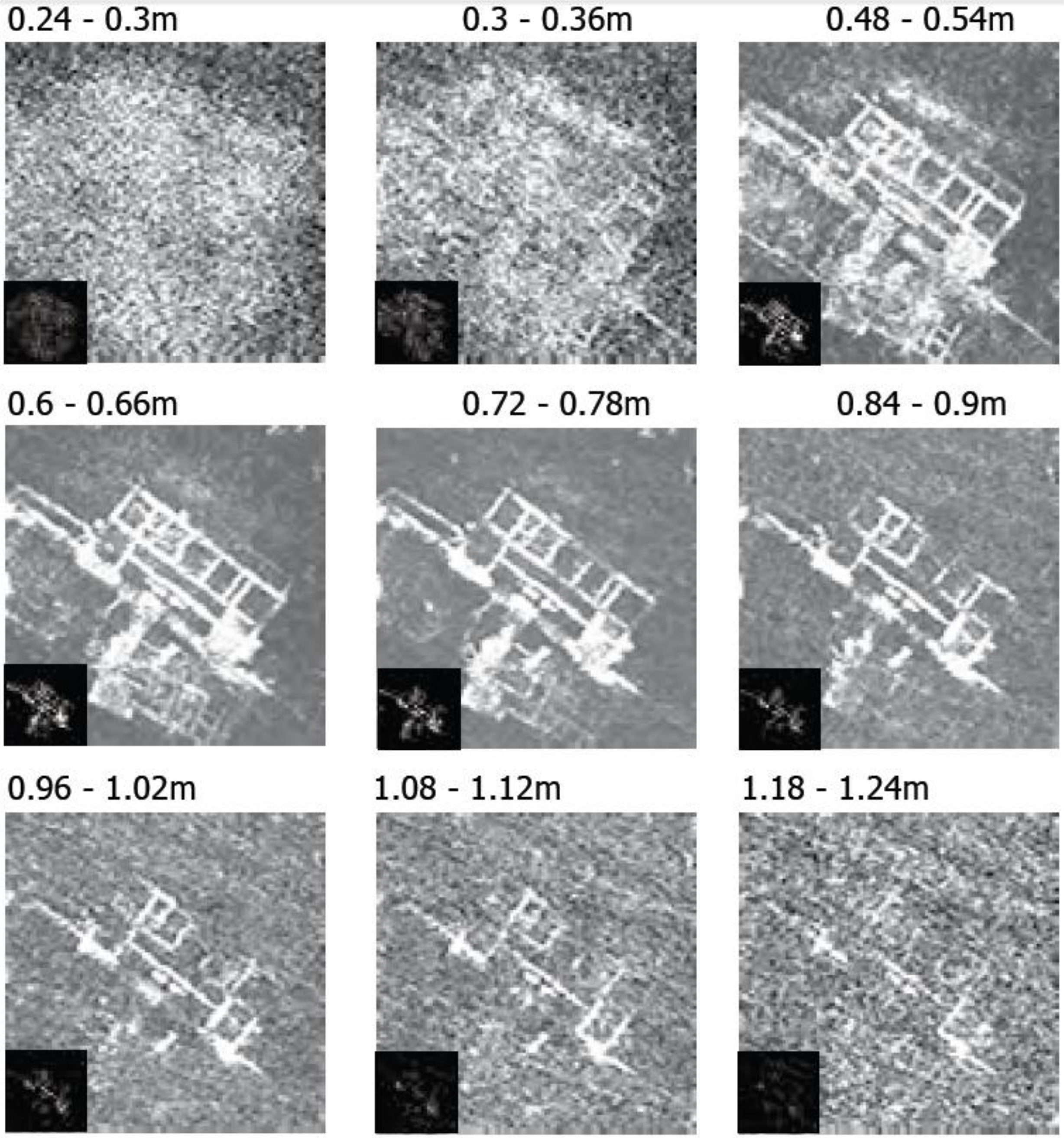

Figure 7. A GPR time-slice display of survey results recorded for the Dunkirt Barn Roman villa site in Hampshire (© English Heritage).

For example a 50 MHz antenna may penetrate up to 50m or more but would have poor resolution. A 500MHz antenna may only penetrate 1m or less but is capable of resolving very small features (like the flint debris shown in Figure 7). For archaeological purposes, antennae with central frequencies in the range of 200 – 500 MHz are most commonly used.

Which geophysical technique is the best one to use?

Which geophysical technique to use involves the consideration of a number of factors, including things like cost, time frame and, more importantly, environmental conditions. For example, GPR is both expensive and requires a higher level of expertise than resistivity survey, which is the cheapest and easiest to use. However, when it comes to speed and the time to complete a survey, then resistivity is the slowest technique. This means that magnetometry, being much faster, is often used to carry out a large area survey first after which resistivity can be used to survey a smaller, and more targeted, area. Table 1 lists a number of site factors which can influence the ideal choice of technique and indicates the likelihood of a technique being suitable.

Environmental condition	Resistivity	Magnetometry	GPR
Dry conditions	C	N	B
Moist conditions	B	N	C
Saturated conditions	P	N	C
Saline conditions	N	N	P
High % of clay minerals	N	N	P
Abundant non-magnetic rocks	C	N	C
Abundant magnetic rocks	C	P	C
Metallic items on surface, i.e. fences	N	C	N
Buried metallic items, i.e. pipes and cables	N	C	N

B = Best, C = Concerns – may work but not guaranteed, N = No effect, P = Problematic

Table 1. Comparison of technique performance under certain environmental conditions (based on Ernenwein and Hargrave, 2009, p58)

As shown here, resistivity is not the preferred method in very dry conditions, hence it will be best used in the spring or late autumn when moisture levels in the soil are generally higher. The problems caused with GPR when high levels of clay minerals or salts are present in the soil can also be noted. Magnetometry is unsuitable under conditions where magnetic metal features, like iron fences or underground pipes, are present. It also means the operator should not wear clothes or shoes with iron zips or eyelets because these items will be close to the sensors and may interfere with the measuring process.

Finally, the type of archaeological feature present, or sought for, can have an effect and certain techniques do not work well under some conditions. Table 2 summarises the situation with some common features.

Feature	Resistivity	Magnetometry	GPR
Large storage pits (> 2m diam)	y	Y	Y
Small pits (< 2m diam)	?	Y	y
Post holes (< 0.5m diam)	n	y	y
Prehistoric ring gullies	n	Y	N
Ditches (< 2m wide)	y	Y	n
Large ditches (> 2m wide)	y	Y	?
Paleo-channels	y	y	Y
Ridge and furrow	Y	Y	N
Hearths	N	Y	N
Kiln and furnaces	N	Y	?
Roads/tracks	y	y	?
Floors	y	Y	Y
Robber/foundation trenches	Y	y	?
Masonry foundations (non-magnetic)	?	Y	Y
Brick foundations	y	Y	Y
Graves with voids	?	y	Y

Y = Recommended, y = Works OK in many cases,? = may work well but another technique might be preferable, n = not usually recommended, N = Not effective

Table 2. The effect of feature type on the appropriate choice of technique. (Taken from English Heritage, 2008, p14)

From these Tables it is possible to conclude that none of the three techniques considered in this article is an ideal, universal method of carrying out archaeological surveys. For this reason the techniques are better considered as being complementary ones, each suited to certain activities but not all. As a general rule, magnetometry and GPR systems are used for large scale surveys while resistivity is used for smaller surveys over features indicated by the other two.

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Further reading

There are a number of publications which provide a fuller description of geophysical survey.

Gaffney, C and Gater, J. A 2006, *Revealing the buried past – Geophysics for archaeologists*, Stroud, Tempus.

English Heritage, 2008, *Geophysical Survey in Archaeological Field Evaluation*, Swindon, English Heritage.

Ernenwein, E. G and Hargrave, M. L 2009, *Archaeological Geophysics for DoD Field Use: a Guide for New and Novice Users.* Downloadable from the website:

www.cast.uark.edu/assets/files/PDF/**ArchaeologicalGeophysicsforDoDFieldUse**.pdf

Reference

Linford, N., Linford, P., Martin, M and Payne, A. 2006, “Geophysical evidence for plough damage”, *Research News, Issue 3*, 3 – 5, Swindon, English Heritage