Castle Hill Farm

Drax

Geophysical survey

MAH100

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Client

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Drax

Geophysical survey

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Executive Summary

Met Surveys was commissioned by Mr. Mark Fletcher of Matrix Archaeology to carry out a combined resistance, magnetometry and ground penetrating radar (GPR) survey at Castle Hill Farm, Drax. The survey was undertaken to investigate the presence and extent of potentially significant archaeological features.

The site is on the southern edge of the village of Drax, and comprises a 19th century farmhouse and disused farm buildings. Grass lawns are located to the north and west of the farm buildings, with hard standing and short grass to the east. This is surrounded by woodland and scrub. The whole area lies on a moated platform which is a Scheduled Ancient Monument (SM30108), and is possibly the site of the medieval castle and manor of Drax.

A Geoscan RM15 resistance meter was used for the resistivity component of the survey, a Bartington Grad601-2 gradiometer for the magnetic survey, and a Mala Geosciences Ramac X3M with 250MHz antennae for the ground penetrating radar survey.

Both resistance survey and GPR successfully located anomalies within the survey areas. The magnetic survey proved less successful due to the proximity of buildings; however anomalies were detected which aided in the interpretation of the results of the other techniques.

A large number of anomalies have been detected indicating different kinds of ground disturbance – much of this may be modern or have been formed during the different stages of construction of the farmhouse and outbuildings over the last few hundred years, however certain anomalies may relate to earlier occupation.

A broad area of low resistance along the northern edge of Area 1 is likely to correspond to the infilled moat (Anomaly 3). High resistance features detected within this feature may correspond to rubble or similar deposits infilling the moat (Anomaly 4). Circular features of low resistance (Anomaly 5) situated on the southern edge of the moat are of unknown origin, but one of these features is cut by a feature known to correspond to a wall demolished in the late 19th or early 20th century.

Anomalies detected by magnetic survey, resistance survey and GPR (Anomaly 1, 8 and A) all suggest the presence of a broad infilled ditch traversing Area 2 on an east-west alignment. GPR results suggest this ditch may have areas of large, loosely compacted, rubble deposits, leading to voiding. Other sections of the ditch may have been covered; a possible explanation is that old editions of O.S maps show the platform with some sections of the moat causewayed, inner ditches may also have been causewayed to aid access.

A further ditch-like feature, possibly also infilled, may run north-south along the western edge of farm outbuildings in Area 2 (Anomalies 10 and C)

High resistance linear anomalies (Anomalies 9, 12 and B) which correspond to hyperbolic anomalies detected by GPR may reflect wall footings, alignments of masonry or large pipes.

A parallel series of linear low and high resistance anomalies, also detected by GPR exist at the southern end of Area 3 (Anomalies 13, D and E). These anomalies may represent compacted surfaces and ditch-like features, although the possibility of their having been

formed by heavy machinery during the construction of the Dutch barn or by the passing of heavy traffic can not be disregarded.

Many other discrete anomalies have been detected throughout the survey area by resistance survey and GPR. These anomalies almost certainly represent buried materials of lower conductivity than the surrounding soil matrix; however the exact nature and origin of these anomalies can not be established.

The results and subsequent interpretation of data from geophysical surveys should not be treated as an absolute representation of the underlying archaeological and non-archaeological features. Features that do not produce a measurable geophysical response or those masked by other features may not be detectable. Confirmation of the presence or absence of features can only be achieved by direct investigation of sub-surface deposits.

Features, especially linear features, may relate to underground utility apparatus such as pipes or gas tanks. Always exercise caution when excavating.

1. Introduction

1.1 Met Surveys was commissioned by Mr. Mark Fletcher of Matrix Archaeology to carry out a combined resistance, magnetometry and ground penetrating radar (GPR) survey at Castle Hill Farm, Drax, in advance of a proposal for refurbishment and rebuilding of existing farm buildings together with the provision of new car parking and access roads.

1.2 The survey was undertaken to investigate the nature and extent of any sub-surface features of potential archaeological significance within the proposed development area, so as to enable an informed assessment of the archaeological impact of the development proposals.

1.3 The site lies on the southern edge of the village of Drax, and comprises a 19th century farmhouse and disused farm buildings. Grass lawns are located to the north and west of the farm buildings, with hard standing and short grass to the east. This is surrounded by woodland and scrub. The farm buildings are located on the platform of a medieval moated site, which is a Scheduled Ancient Monument (SM 30108).

1.4 The underlying solid geology of the site comprises undifferentiated Permian and Triassic sandstone, overlain by glaciofluvial or river terrace deposits. Soils within the area are of the Wick 1 association.

1.5 The survey was undertaken in accordance with a Written Scheme of Investigation provided by Matrix Archaeology Ltd. and following recommendations outlined in the English Heritage Research and Professional Services Guideline No.1: Geophysical survey in archaeological evaluation (David 1995); the Institute of Field Archaeologists Paper No.6: The use of geophysical techniques in archaeological evaluations (Gaffney et al. 2002) and the Archaeology Data Service: Geophysical data in archaeology: A guide to good practice (Schmidt 2001).

1.6 The survey areas measured approximately 0.25ha in total, and comprised mostly short grass, with some areas of hard-standing. All areas were surveyed using all methods, although coverage and effectiveness of the resistance and geomagnetic techniques in the southeastern area was limited by the presence of hard standing and a Dutch barn.

1.7 The resistance survey was undertaken on a 20m grid system, with a traverse interval of 1m and a sample interval of 0.5m. The magnetometer survey was also carried out on a 20m grid, with a traverse interval of 1m and a sample interval of 0.25m. The GPR survey was carried out on 1m orthogonal survey grids, except for the northernmost area which was surveyed using a grid spacing of 2m, surveying profiles parallel to a baseline and then perpendicular to it. A reading was taken every 2cm along each profile. The location and extent of the geophysical surveys is shown in drawing MAH100_(1).

1.8 Certain areas could not be surveyed, due to the presence of trees or other obstructions, and these are marked on the drawings in blue. Resistance surveys can generally not be performed over hard standing ground, as there is no reliable electrical contact with the ground, and this further restricted some areas from survey.

1.9 The site code is MAH100. The project archive is currently held by Met Surveys, and will be transferred to North Yorkshire County archive in due course. Met Surveys is registered with the **O**nline **A**cces**S** to the **I**ndex of archaeological investigation**S** project (**OASIS**). The OASIS ID number for this project is **metsurve1-20982**.

2. Methodology and presentation

Survey Methodology

2.1 The survey was undertaken in accordance with a Written Scheme of Investigation provided by Matrix Archaeology Ltd. and following recommendations outlined in the English Heritage Research and Professional Services Guideline No.1: Geophysical survey in archaeological evaluation (David 1995); the Institute of Field Archaeologists Paper No.6: The use of geophysical techniques in archaeological evaluations (Gaffney et al. 2002) and the Archaeology Data Service: Geophysical data in archaeology: A guide to good practice (Schmidt 2001).

2.2 Survey grid baselines were established in each of the survey areas by means of a Leica TCR 705 total station. These baselines were then tied in to previously established survey stations [EL2A, EL05 and EL06] such that data could be compared and presented alongside a previous topographic survey of the area [CASTLEHILLFARMTOPO.dwg] provided by the client.

2.3 Given the high potential for archaeological remains within the area, a comprehensive survey methodology employing geomagnetic and electrical resistance techniques as well as ground penetrating radar was used, to maximise the possibility of detecting sub-surface features.

2.4 Measurements of the vertical geomagnetic field gradient were taken using a Bartington Grad601-2 magnetic gradiometer with internal data logger. The instrument was checked for electronic and mechanical drift at regular intervals. Data were logged in 20m grid units, in a zig-zag traverse pattern with a traverse interval of 1m, at a sample interval of 0.25m and at a sensitivity of 0.1nT, resulting in a total of 1800 readings per grid.

2.5 Measurements of electrical resistance were determined using a Geoscan RM15D resistance meter with automatic logging of the data. A zig-zag traverse scheme was employed and data were logged in 20m grid units. The instrument sensitivity was set to 0.1ohm, the sample interval to 0.5m and the traverse interval to 1.0m, thus providing 800 sample measurements per 20m grid unit.

2.6 A Mala Geosciences Ramac X3M with 250MHz antennae was used for the ground penetrating radar survey. This system was chosen because it gives a depth penetration of approximately 3.0m whilst maintaining a high degree of spatial resolution. As the primary aim of this survey was to locate and identify archaeological features this combination of good resolution and moderate depth penetration was essential.

2.7 The GPR survey was carried out on a site grid with profiles positioned 1m apart (except in the northernmost area, where profile spacing was 2m) in both the X and Y axes and readings taken every 0.02m.

Data Processing

2.8 Geoplot v.3 software was used to process the geophysical data from the resistance and gradiometer surveys and to produce both continuous tone greyscale images and trace plots of the raw data. The data had a zero mean traverse function (grid balancing) applied where necessary. The data was also clipped and despiked, then interpolated for presentation. Some grids had a low pass filter applied to enhance weaker features.

2.9 The GPR data were processed and analysed using Sandmeier Software Reflex-win v3.5. The data were initially depth corrected to allow for the gap between the transducer and the ground surface and then filtered to highlight anomalies. This filtering involved performing a high and low band pass filter to eliminate unwanted low and high frequency signals, background noise reduction to remove horizontal background noise and noise added by the GPR system, and increasing the gain of responses proportional to their depth.

2.10 Each GPR profile was examined visually and anomalies of interest, such as hyperbolae or areas of strong frequency variations related to sub-surface horizontal interfaces, were picked. These points were converted to a .dxf file containing X and Y co-ordinates and an approximate depth value using in-house software (METPCK2Dxf) and imported into AutoCAD LT (© AutoDesk). Points of common interest were linked to produce the interpretation.

Interpretation

2.11 The geophysical data and interpretations are presented in drawings MAH100_(2) – (6). In the greyscale images, positive magnetic or high resistance anomalies are displayed as dark grey and negative magnetic or low resistance anomalies as light grey. A palette bar relates the greyscale intensities to anomaly values in nT/m or ohm.

2.12 Colour-coded geophysical interpretation plans are provided. Anomaly types which may be distinguished in the data fall into these categories:

positive magnetic	regions of anomalously high or positive magnetic field gradient, which may be associated with high magnetic susceptibility soil-filled structures such as pits and ditches (*linear trends or areas of enhanced response*).
negative magnetic	regions of anomalously low or negative magnetic field gradient, which may correspond to features of low magnetic susceptibility such as wall footings and other concentrations of sedimentary rock or voids (*linear trends or areas of enhanced negative response*). .
dipolar magnetic	paired positive-negative magnetic anomalies, which usualy reflect ferrous or fired materials (e.g. fences and service pipes) and/or fired structures such as kilns or hearths, as well as often signifying areas of disturbance involving fired and ferrous material e.g. building rubble (*isolated or concentrations of responses*).
high resistance	regions of anomalously high resistance, which may reflect foundations, tracks, paths and other concentrations of stone or brick rubble.
low resistance	regions of anomalously low resistance, which may be associated with soil-filled features such as pits and ditches.

2.13 A more detailed technical summary on the theory and survey methodology of resistivity, magnetometry and ground penetrating radar can be found in Appendices 1, 2 and 3 respectively.

The interpretative figures do not provide an exact representation of the sub-surface and they should be viewed in conjunction with the relevant discussion section and with the information contained in the Appendices.

3. Results and discussion

Magnetic Gradient (MAH100_(2).dwg / MAH100_(4).dwg)

3.1 Large areas of magnetic disturbance are present in all of the survey areas, characterised by intensely magnetic dipolar responses. The intense readings measured due to the proximity of buildings, surface features such as manholes and the possible existence of subsurface cables and pipes, mask any subtler anomalies which may result from features of archaeological significance such as pits or ditches. Both Area 1 and most of Area 3 are badly affected by this contamination.

3.2 However, a change in character to this magnetic disturbance is exhibited in Area 2, where dipolar magnetic anomalies are much more mixed as opposed to the more homogenous anomalies detected close to buildings (especially apparent in proximity to the Dutch barn in Area 3). These mixed dipolar responses exhibit a vague linear trend aligned east-west and leading towards Area 3 (Anomaly 1). This broad linear concentration of magnetic anomalies correspond to anomalies detected using resistance survey and GPR. This type of concentration of dipolar anomalies suggests the presence of ferrous and fired material, possibly building rubble, and may represent the infilling of a broad ditch feature.

3.3 A less intensely concentrated spread of dipolar magnetic anomalies (Anomaly 2) in the northeast corner of Area 2 may reflect building rubble originating from the demolition of prior buildings known to have existed in this location

Resistance (MAH100_(3).dwg / MAH100_(5).dwg)

3.4 A broad region of lower resistance aligned roughly northwest-southeast along the northern edge of Area 1 (Anomaly 3) may correspond to the infilled moat. High resistance features (Anomaly 4) found within this low resistance area may be caused by stone or rubble deposits, or other materials of lower conductivity when compared to the surrounding matrix, within these moat deposits.

3.5 Two rough circular features exhibiting lower resistance have been detected (Anomaly 5), one directly on the margin of the low resistance area, and one approximately 6.5 metres to the southwest. These anomalies are of uncertain origin but one seems to be cut by Anomaly 6 and therefore is of earlier origin.

3.6 A linear anomaly of high resistance (Anomaly 6) found in Area 1 corresponds to the projected wall line of a demolished outbuilding is almost certainly a wall footing.

3.7 Discrete high resistance anomalies to the south of this linear feature are most likely to be caused by features pertaining to the adjacent building's foundations.

3.8 A high resistance linear feature aligned north-south (Anomaly 7) relates to grassed over brick and concrete, possibly covering a drain, as a broken inspection cover was located at its northern end.

3.9 To the south of Area 2, the character of the background resistance changes and becomes much more variable. This change can also be seen in Area 3 and may result from ground disturbance, or the presence of varied deposits.

3.10 A broad swathe of areas of lower resistance, together with high resistance features runs east-west along Area 2 (Anomaly 8). These anomalies correspond to the location of anomalies detected using both magnetic and GPR techniques and may reflect a broad infilled ditch or ditches with areas of high resistance possibly reflecting masonry or rubble deposits.

3.11 A linear alignment of high resistance anomalies aligned northwest-southeast has been detected in the southern part of Area 2 (Anomaly 9). These anomalies correspond roughly to Anomaly B detected by GPR and may reflect wall foundations.

3.12 In the northern part of Area 2, west of the outbuildings, several areas of high resistance have been located (Anomaly 11) which may reflect subsurface features and could relate to Anomaly 2 detected by magnetic survey. A high resistance feature runs alongside the farm outbuildings to the east (Anomaly 10). GPR has detected a ditch-like feature in the same area; the high resistance of this feature suggests that it too has been infilled with stone or rubble similar to Anomaly 8.

3.13 An area of anomalous resistance values at the extreme northern end of Area 3 reflects the presence of hard-standing where the electrodes could not make sufficient ground contact.

3.14 Discrete high resistance features within Area 3, to the east of Area 2, may be caused by areas of stony deposits, rubble or masonry. A linear high resistance anomaly (Anomaly 12) aligned roughly northeast-southwest may correspond to a wall footing or similar.

3.15 At the southern end of Area 3 broad parallel features of high and low resistance have been detected (Anomaly 13). The high resistance areas correspond to anomalies detected using GPR, and may reflect surfaces or compacted areas, with the low resistance areas on either side possibly reflecting ditch-like features. Whilst possibly being of archaeological significance these features may also result from the construction of the Dutch barn in Area 3.

Ground Penetrating Radar (GPR) (MAH100_(6).dwg

3.16 The interpretation of the GPR data is shown in drawing MAH100_(6).

3.17 Timeslice analysis effectively sums the reflected energy within a time 'window' and produces an amplitude contour plot to enable relative comparison of surveyed areas. Using a velocity of 0.08m/ns (the average for soil and pastoral land) we can calculate an approximate depth. The results from the timeslice analysis did not provide any clearly defined features due to the disturbed nature of the site therefore each traverse was examined individually and the detail from these is represented in drawing MAH100_(6)

3.18 It should be noted that some features cast a reflective 'shadow' in the GPR data that appears to show anomalies extending to a greater depth than they actually do. The depths given for the area anomalies should be considered as maximum and minimum and it is probable that the feature will actually lie somewhere between the two.

3.19 Several main features were identified from the GPR data. Anomaly A dominates the data set in Area 2, west of the farmhouse outbuildings. The response in places is similar to that associated with a large in-filled ditch and is associated with heavy disturbance. Areas of voiding are also present and are linked with the presence of horizontal layers across the apparent ditch structure. Here the feature could be suggested to be more of a culvert.

3.20 The anomalies labelled as B form linear features associated with very large hyperbolae of a similar size and depth and could represent the presence of sub-surface features.

3.21 Anomaly C is very similar in composition to anomaly A, running north along the side of the farmhouse outbuildings in Area 2.

3.22 Anomaly D has the characteristic of a surface with shallow flanking ditches at each side, although this is not consistent, whilst anomaly E is a sub-surface feature that slopes from east to west.

3.23 One of the most noticeable aspects of the GPR data is the number of ‘hyperbolae’ anomalies present. The weaker examples have not been represented on the final interpretation as they are most probably associated with tree roots.

3.24 The stronger hyperbolae are shown in blue and could be associated with large tree roots or sub-surface features. Additional hyperbolae anomalies can be seen in purple and have been labelled as ‘large hyperbolae’. These are much more substantial and are more likely to be associated with sub-surface features. Both type of hyperbolae are present throughout the survey areas and are also present within the heavily disturbed areas.

3.25 Also noticeable is the large areas of disturbance throughout the survey areas. The disturbance shown on the drawing has been categorised as ‘disturbed response’ and ‘heavily disturbed response’.

3.26 The disturbed response features appear more compacted and uniform than the background disturbance whilst the heavily disturbed response is much more concentrated and intense in amplitude, often containing large hyperbolae. The disturbance to the south of the farmhouse outbuildings and the heavy disturbance associated with Anomaly A could represent the presence of a ditch feature. The disturbance and heavy disturbance to the southeast of the farmhouse outbuildings could be associated with the same ditch feature although they are not as uniform in composition.

3.27 The large areas of heavily disturbed response to the front of the farmhouse could be associated with the backfilled part of the north limb of the moat. This area is very intense in appearance and contains a large number of substantial hyperbolae that could originate from fill material. These are generally in the same locations as the disturbances in the magnetic and resistivity data, and are most likely caused by the same features.

3.28 A large area of concentrated reflections can be seen to the west of the farmhouse with several smaller examples present around the Dutch barn. Here the response is strong and is indicative of a previous ground surface or sub-surface feature.

4. Conclusions

4.1 Both resistance survey and GPR successfully located anomalies within the survey areas. Magnetic survey proved less successful due to the proximity of buildings; however anomalies were detected which aided in the interpretation of the results of the other techniques.

4.2 A large number of anomalies have been detected indicating different kinds of ground disturbance – much of this may be modern or have been formed during the different stages of construction of the farmhouse and outbuildings over the last few hundred years, however certain anomalies may relate to earlier occupation.

4.3 A broad area of low resistance along the northern edge of Area 1 is likely to correspond to the infilled moat (Anomaly 3). High resistance features detected within this feature may correspond to rubble or similar deposits infilling the moat (Anomaly 4). Circular features of low resistance (Anomaly 5) situated on the southern edge of the moat are of unknown origin, but one of these features is cut by a feature known to correspond to a wall demolished in the late 19th or early 20th century.

4.4 Anomalies detected by magnetic survey, resistance survey and GPR (Anomaly 1, 8 and A) all suggest the presence of a broad infilled ditch traversing Area 2 on an east-west alignment. GPR results suggest this ditch may have areas of large, loosely compacted, rubble deposits, leading to voiding. Other sections of the ditch may have been covered; a possible explanation is that old editions of O.S maps show the platform with some sections of the moat causewayed, inner ditches may also have been causewayed to aid access.

4.5 A further ditch-like feature, possibly also infilled, may run north-south along the western edge of farm outbuildings in Area 2 (Anomalies 10 and C)

4.6 High resistance linear anomalies (Anomalies 9, 12 and B) which correspond to hyperbolic anomalies detected by GPR may reflect wall footings, alignments of masonry or large pipes.

4.7 A parallel series of linear low and high resistance anomalies, also detected by GPR exist at the southern end of Area 3 (Anomalies 13, D and E). These anomalies may represent compacted surfaces and ditch-like features, although the possibility of their having been formed by heavy machinery during the construction of the Dutch barn or by the passing of heavy traffic can not be disregarded.

4.8 Many other discrete anomalies have been detected throughout the survey area by resistance survey and GPR. These anomalies almost certainly represent buried materials of lower conductivity than the surrounding soil matrix; however the exact nature and origin of these anomalies can not be established.

The results and subsequent interpretation of data from geophysical surveys should not be treated as an absolute representation of the underlying archaeological and non-archaeological features. Features that do not produce a measurable geophysical response or those masked by other features may not be detectable. Confirmation of the presence or absence of features can only be achieved by direct investigation of sub-surface deposits.

Features, especially linear features, may relate to underground utility apparatus such as pipes or gas tanks. Always exercise caution when excavating.

5. References

David, A, 1995 *Geophysical survey in archaeological field evaluation,* Research and Professional Services Guideline **1**, English Heritage

Gaffney, C, Gater, J & Ovenden, S, 2002 *The use of geophysical techniques in archaeological evaluations*, Technical Paper **6**, Institute of Field Archaeologists

Schmidt, A, 2001 *Geophysical Data in Archaeology: A Guide to Good Practice*, Archaeology Data Service, Arts and Humanities Data Service

Matix Archaeology Ltd. 2006 Castle Hill Farm, Drax, Near Selby, North Yorkshire: archaeological Desk based Assessment Report 2006-12, Matrix Archaeology Ltd., Manchester

Appendix 1

Resistance Survey: Technical Information and Methodology

1. Soil Resistance

1.1 The electrical resistance of the upper soil horizons is predominantly dependant on the amount and distribution of water within the soil matrix. Buried archaeological features, such as walls or infilled ditches, by their differing capacity to retain moisture, will impact on the distribution of sub-surface moisture and hence affect electrical resistance. In this way there may be a measurable contrast between the resistance of archaeological features and that of the surrounding deposits. This contrast is needed in order for sub-surface features to be detected by a resistance survey.

1.2 The most striking contrast will usually occur between a solid structure, such as a wall, and water-retentive subsoil. This shows as a resistive high. A weak contrast can often be measured between the infill of a ditch feature and the subsoil. If the infill material is soil it is likely to be less compact and hence more water retentive than the subsoil and so the feature will show as a resistive low. If the infill is stone the feature may retain less water than the subsoil and so will show as a resistive high.

1.3 The method of measuring variations in ground resistance involves passing a small electric current (1mA) into the ground via a pair of electrodes (current electrodes) and then measuring changes in current flow (the potential gradient) using a second pair of electrodes (potential electrodes). In this way, if a structural feature, such as a wall, lies buried in a soil of uniform resistance much of the current will flow around the feature following the path of least resistance. This reduces the current density in the vicinity of the feature, which in turn increases the potential gradient. It is this potential gradient that is measured to determine the resistance. In this case, the gradient would be increased around the wall giving a positive or high resistance anomaly.

1.4 In contrast a feature such as an infilled ditch may have a moisture retentive fill that is comparatively less resistive to current flow. This will increase the current density and decrease the potential gradient over the feature giving a negative or low resistance anomaly.

2. Survey Methodology

1.5 The most widely used archaeological technique for earth resistance surveys uses a twin probe configuration. One current and one potential electrode (the remote or static probes) are fixed firmly in the ground a set distance away from the area being surveyed. The other current and potential electrodes (the mobile probes) are mounted on a frame and are moved from one survey point to the next. Each time the mobile probes make contact with the ground an electrical circuit is formed between the current electrodes and the potential gradient between the mobile and remote probes is measured and stored in the memory of the instrument.

1.6 A Geoscan RM15 resistance meter was used during this survey, with the instrument logging each reading automatically at 1m intervals. The mobile probe spacing was 0.5m with the remote probes 15m apart and at least 15m away from the grid under survey. This mobile probe spacing of 0.5m gives an approximate depth of penetration of 1m for most archaeological features and so a soil cover of greater than 1m may mask, or significantly attenuate, a geophysical response.

3. *Data Processing and Presentation*

1.7 All of the illustrations incorporating a digital map base (Figures 2 to 9) were produced in AutoCAD 2000 (© Autodesk).

1.8 The resistance data is presented in this report in greyscale format with a linear gradation of values and was obtained by exporting a bitmap from the processing software (Geoplot v3.0; Geoscan Research) into AutoCAD 2000. The data in Figures 2 and 3 is processed with a zero mean traverse function (grid balancing) applied where necessary. The data was also clipped and despiked, then interpolated for presentation. Some grids had a low pass filter applied to enhance weaker features. but has been interpolated by a value of 0.5 in both the X and Y axes using a sine wave (x)/x function to give a smoother, better defined plot. All greyscale plots are displayed using a linear incremental scale.

Appendix 2

2 Magnetic survey: technical information

2.1 Magnetic properties

2.1.1 The magnetic survey is based on the fundamental principle that all materials have magnetic properties (whether directly observable or not). There are two properties that are of importance in archaeology.

2.1.2 The property of most importance is **magnetic susceptibility**. This is generally an indicator of ferrous mineral concentration and it also determines how readily a material becomes magnetised when it is in the presence of a magnetic field.

2.1.3 ***Anthropogenic*** (human) activity can change the ferrous material that is present in soils into more magnetic forms (***enhancement***) and it can redistribute the ferrous material to create areas of lower or higher magnetic susceptibility. The presence or absence of anthropogenic activity can therefore be detected by measuring the background magnetic susceptibility of an area and looking for variations (***anomalies***) within it. The magnetism can be measured using a magnetic susceptibility meter or a magnetometer.

2.1.4 Natural enhancement of ferrous material can occur and this is also important in detecting archaeological features. Topsoil generally has a higher magnetic susceptibility than the subsoil and underlying geology because the ferrous material within it is oxidised into more magnetic compounds. Features associated with anthropogenic activity, such as pits or ditches, may become infilled by the more magnetic topsoil. It is the ***contrast*** between the magnetic susceptibility of the infill material and the magnetic susceptibility of the surrounding matrix that causes the magnetic anomaly.

2.1.5 The second magnetic property that is of importance in archaeology is **thermoremnant** magnetism. This is caused by weakly magnetised materials being heated above, and then allowed to cool through, the Curie Point. This is a specific temperature for different materials at which the heat results in the original magnetic orientation being wiped out. As it cools back through this point the material acquires a permanent magnetisation that is associated with the direction of the field in which it cooled (usually the Earth's). Thermoremnace allows such features as hearths and kilns to be readily identified due to their relatively high magnetic signature. It can, however, also cause problems for magnetic surveys over some igneous geologies as these can have a strong thermoremnant magnetisation that masks any changes caused by the magnetically weaker archaeological features.

2.2 Measurement of the Magnetic Field

2.2.1 Instruments that are used to measure a magnetic field are called magnetometers. The fluxgate magnetometer is the most suitable to use in rapid surveys to detect archaeological features. This magnetometer consists of high magnetic permeability cores that have coils wrapped around them. As an alternating current is passed through the cores they are driven in and out of magnetic saturation. Every time they come out of saturation an external field causes an electric pulse proportional to the field strength that affects them.

2.2.2 Although this is a cyclic measuring system the whole process takes milliseconds and is therefore effectively continuous for archaeological survey purposes. The major problem with it is that it is highly direction sensitive as it only measures the magnetic field component parallel to its axis. This means that any tilt in the sensor leads to a change in the reading. This is compensated for by using **a gradiometer** system, where two sensors are used, and by fine-tuning the detector alignments at each individual site to achieve the minimum direction sensitivity. The fluxgate gradiometer is the standard magnetometer used in archaeological surveys.

2.2.3 Magnetic data that is measured in the field in a regular grid system is called ***detailed survey***. This technique generally involves taking readings at predetermined points on a grid. The readings are stored in the memory of the instrument and are later downloaded to computer for processing and interpretation. Met Surveys uses a Bartington Grad601-2 system to collect its geomagnetic data, which currently represents state-of-the-art technology for archaeological prospection.

2.2.4 The Bartington Grad601-2 is a dual sensor instrument, incorporating two Grad-01-1000 gradiometers set at a distance of 1m apart. The sensors within each gradiometer are also spaced 1m apart, rather than the 0.5m found in most fluxgate gradiometers. The configuration of the Grad601-2 provides an increased depth penetration and weaker anomalies are detected with greater resolution, as well as reducing both the time taken and distance walked compared to a conventional fluxgate gradiometer survey.

2.2.5 The Grad-01-1000 sensor is a high-stability fluxgate gradient sensor with a resolution of 0.1nT/m when used on the 100nT/m range and 1nT when used on the 1000nT range. The exceptional temperature stability of this sensor ensures minimal drift during surveys and reduces the need for adjustment and consequently survey time.

2.3 Magnetic Anomalies

2.3.1 The overall geomagnetic field intensity in Britain is about 48000 nanoTeslas (nT). When the magnetic field is measured across a site the reading varies depending on the average magnetic susceptibility of the pedology and geology. Archaeological features can cause changes in this background measurement that range from about 500nT for thermoremnant magnetic features to as little as 0.2nT for features with a low magnetic contrast to the surrounding matrix. Comparing these values it can be seen that very sensitive equipment is needed to measure these changes.

2.3.2 All anomalies will have a positive and negative magnetic component relative to the background geomagnetic field. The responses from material with a higher magnetic susceptibility than the background will have usually have a larger positive component and can generally be described as a positive anomaly. As discussed above the majority of archaeological features have a higher magnetic susceptibility than the background and will therefore be observed as positive anomalies. Features that have thermoremnant magnetism will also have a positive response.

2.3.3 Some features can manifest themselves as **negative** anomalies, which conversely means that the response is negative relative to the mean magnetic background. Such negative anomalies are often very faint and are commonly caused by modern, non-ferrous, features such as water pipes or drains. Infilled natural features may also appear as negative anomalies on some geologies.

2.3.4 Material that has a high ferrous content can have very strong positive and negative components. This type of response is called a **dipolar anomaly**.

2.3.5 The responses mentioned above can be further sub-divided and a possible interpretation can be made based on the anomaly type and morphology. There are often difficulties in interpreting the origin of anomalies and so anomalies are generally described as probable, possible or unknown. It should be noted that anomalies that are interpreted as modern in origin might be caused by features that are present in the topsoil or upper layers of the subsoil. Removal of soil to an archaeological or natural layer can therefore remove the feature causing the anomaly.

2.3.6 The general categories of magnetic anomaly are:

- **Isolated dipolar responses** ('Iron spikes')

  This response is characterised by a rapid positive / negative variation in the magnetic response resulting in a 'spike' profile. These anomalies are typically caused by ferrous material either on the surface or in the topsoil. A near-surface archaeological artefact could produce an iron spike response but the vast majority of these anomalies, even on archaeological sites are caused by modern ferrous material and so little importance is usually given to them.

- **Areas of magnetic disturbance** (a concentration of dipolar responses)

  This type of anomaly is characterised by an area of very strong, 'spiky' variations in the magnetic background. These anomalies can have several causes, from concentrations of near-surface ferrous or fired material to surface features such as ferrous fencing or tipped material. A modern origin is again usually assumed unless there is other supporting information.

- **Linear trend** (positive or negative anomalies)

  This is usually a weak or broad linear anomaly of unknown cause or date. An agricultural origin, either ploughing or land drains is a common cause.

- **Areas of magnetic enhancement** (positive isolated or areas of positive response)

  These responses do not have the characteristic spike of the dipolar anomalies but instead are characterised by a general increase in the magnetic background over a localised area. Pedological variations or natural geomorphological features, such as palaeochannels or infilled natural features on certain geologies, can produce areas of magnetic enhancement, as can infilled discrete archaeological features, such as pits or post holes, or areas of anthropogenic activity. Kilns and other industrial features can produce strong areas of magnetic enhancement, with the former often being characterised by a strong, positive double peak response. Modern ferrous material in the subsoil can also give a similar response. Magnetic enhancement can therefore be associated with natural or anthropogenic processes and it can often be very difficult to establish an anthropogenic origin without intrusive investigation or other supporting information.

- **Linear and curvilinear anomalies** (positive, negative and dipolar)

  These anomalies have a variety of origins. They are commonly caused by agricultural practice, such as former field boundaries, ploughing, both modern and earlier ridge and furrow regimes or land drains. Modern features generally cause negative and dipolar anomalies.

  Infilled archaeological ditches usually produce a positive anomaly and so if a pattern can be seen in the linear or curvilinear anomalies that corresponds with the morphology of an archaeological field system or settlement then it is often possible to identify archaeological sites.

Appendix 3

3 Ground penetrating radar: technical information

3.1 Theoretical background

3.1.1 A short pulse (or wave) of electromagnetic (EM) energy is emitted from a transmitter antenna, the frequency of which is determined by the characteristics of the system, and propagates through a medium. Any object or interface that involves significantly contrasting electromagnetic (dielectric) properties, and has sufficient physical dimensions, will cause a partial reflection or scattering of the incident EM energy. The greatest reflections occur where there is an abrupt change in dielectric properties. A receiver antenna detects the reflected signals and the travel times of the initial and reflected pulses, along with their amplitudes. These are recorded and converted into pseudo-depth measurements, giving a depth section showing the variations in EM properties of the sub-surface materials. The travel time is generally less than a millisecond for penetration depths of several metres.

3.1.2 The velocity of an EM wave is dependant on the physical properties of the material through which it passes and the velocity will therefore vary as it passes through the ground. The exact composition of the sub-surface can never be known and so the conversion of the two-way travel time into a depth measurement can only be an approximation. The accuracy of this approximation depends on how closely the velocity estimate is to the actual ground conditions.

3.1.3 The interaction of the EM waves with the materials through which they propagate is complex but the two properties that are of most importance are the material conductivity and dielectric constant. These properties control the velocity of the wave and how much of its energy is absorbed over distance (attenuation). They also govern the amplitude and forms of reflections generated by interfaces and hence determine how a feature will appear in the data set. The lower the dielectric constant of a material the faster the propagation of energy and the lower the attenuation. Water has a high dielectric constant and so the moisture content of a material is important in determining the depth of penetration.

3.1.4 The conductivity of a material also contributes to the rate of signal attenuation. Highly conductive materials transfer the GPR pulse into heat energy, thus reducing signal strength. Saturated or clay rich soils have high conductivities and therefore cause significant attenuation in the pulse.

3.1.5 The attenuation, and hence effective depth penetration, is also dependant on the frequency of the EM wave. Higher signal frequencies provide greater resolution but are attenuated more heavily whereas the lower signal frequencies can penetrate deeper but with a subsequent loss in resolution. Small features are therefore more difficult to detect at depth. The antennae frequencies can range from less than 100MHz, for deep geological surveys, to more than 1GHz for shallow structural inspections.

3.2 Criteria for detection

3.2.1 Several criteria must be satisfied before a GPR survey is undertaken. These criteria will establish whether a GPR survey is likely to be successful and satisfy its objectives. First, the target body must vary in conductivity and dielectric constant from the background material in the direction of the survey. Second, the anomaly generated must be large enough to be detected. Meter resolution and expected noise must be considered at this stage. Third, the anomaly generated must be more able to characterise the target body than other geophysical properties (magnetism, gravity, etc.) otherwise GPR is not right tool for job (although a GPR survey could be used in conjunction with these other techniques to further constrain the anomalous body).

3.2.2 The success of a GPR survey is limited by the site-specific ground and sub-surface conditions. Variations in the surface topography can degrade the data, whilst larger changes can result in the energy being propagated in misleading directions. The sub-surface material also plays a very important role in the success of a GPR survey. Materials with high moisture content will attenuate the signal, with a resultant decrease in depth penetration. Penetration in pedologies, such as clay rich soils, can be severely restricted. Standing water on the ground surface will also severely degrade the data. Made ground may contain a multitude of individual reflectors, such as areas of rubble infill, which can increase the data noise and make interpretation more difficult. Heterogeneous ground also results in a greater scattering effect and so the signal strength is decreased. The presence of steel or other highly conductive material, such as in reinforced concrete, can also severely attenuate a signal or produce very strong reflections that mask responses from other objects beneath them.

3.3 Instrumentation

3.3.1 There are a number of different types of instrument available and each one is built to a different specification. Some systems transmit energy in pulses, others in a continuous wave (CW). The form and duration of the energy, the frequency of operation, and the strength of reflected signal that can be detected, the antennae design, and whether the antennae can be moved apart or interchanged with different frequency antennae all vary from system to system. The majority of the systems that are currently on the market have digital recording facilities and a number of them have built in odometers so that data can be linked to an exact point on a traverse line. An experienced operator who has been fully briefed on the likely site conditions can best assesses whether a particular instrument and antennae frequency is suitable to achieve the desired aims of an individual project.

3.4 Survey procedure

3.4.1 As with all geophysical surveys the survey design is critical to obtaining the required level of information. Factors that should be considered are:

- the frequency of the GPR system.
- length, position and orientation of survey lines need to be considered to ensure that the target is clearly imaged with respect to the background.
- the sampling interval needs to be fine enough to resolve the target (aliased) but care should be taken against oversampling as this may have cost and time implications.

3.4.2 As discussed in section 3.1.5 the depth of penetration versus resolution must be considered when selecting the antennae frequency.

3.5 Inherent problems associated with the interpretation of GPR data

3.5.1 One of the main limitations of GPR data is that it can often be difficult to discriminate signals caused by features from background noise. The first signal that a receiver picks up is a very large reflection from the ground surface. Later signals may have components from a number of objects in different positions. The latter occurs because the EM energy is not confined to a narrow beam and so reflections occur from objects that are not immediately below the instrument. Some of the EM energy is also transmitted above ground and so objects on the surface can also affect the data. Because the transmitted EM signal is not made up of a single frequency the elements of the signal are attenuated at different rates and respond slightly differently to the objects that they encounter. These factors combined with possible multiple reflections from single objects result in a very complex received signal. The signal must be processed using specialist software and requires expert interpretation. It should be recognised that because of the level of processing required and the fact that the complex signal interactions can never be fully understood, the displayed data is only an indirect representation of the sub-surface.

3.5.2 As discussed above (Section 3.1.2) the depth estimations obtained from a GPR survey are based upon assumed velocities of the sub-surface material. In the majority of cases accurate site-specific velocities are not available and so average values for different types of stratigraphy must be used. These average values give a good estimation of depth providing that the ground is relatively homogenous. If the composition of the sub-surface is not known or if the ground is heterogeneous then the depth estimations may be inaccurate.

3.7.3. The GPR technique is a guide to the sub-surface dielectric properties of the ground. Its primary aim is to target invasive investigation by identifying anomalous areas. Once ground truth has been established, interpretations can be extrapolated across the site. GPR and geophysics in general, should not be viewed as an alternative to invasive investigation but as a supplementary tool. Preliminary geophysical investigations have the potential to improve the success of an invasive investigation as well as dramatically reduce its cost.