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Archaeological magnetic survey – general methodology and requirements

General survey methodology

It is proposed to carry out the magnetic survey using a Phase Site Investigations Ltd MACS (multi-sensor array cart system) or a Bartington Grad601-2 magnetic gradiometer .

The MACS utilises between four and eight Foerster 4.032 Ferex CON 650 gradiometers with a control unit and data logger. The gradiometers are carried on a non-magnetic cart and usually have a spacing of 0.5 m or 1 m, although other intervals can be adopted. Readings are generally taken generally at between 10 cm and 15 cm intervals. This may increase to 15 cm to 25 cm intervals if an ATV (all terrain vehicle) is used to tow the system.

A Bartington component will be carried out using a Grad601-2 magnetic gradiometer with data logger. The data will be recorded over 30 m by 30 m grids with readings taken on the 100 nT range (0.1 nT sensitivity) at 0.25 m intervals on profiles spaced 1 m apart.

A MACS utilises an RTK GNSS system which means that survey grids do not have to be established. Instead an area is surveyed over a series of continuous profiles and the position of each data point is recorded using an RTK GNSS system.

Grid points for the Bartington survey will be set out and tied-in using a VRS RTK GNSS system to better than 0.05 m accuracy.

A MACS will be used by preference, as it obtains higher quality data, but it cannot be utilised if the ground cover is to uneven or if there is a crop that is higher than approximately 0.5 m (knee high). Ploughed or rutted fields, some harrowed and set-aside fields and fields with a mature crop or dense vegetation will not therefore be suitable for a MACS survey.

The survey will be referenced direct to Ordnance Survey (OS) National Grid and so temporary survey stations (wooden stakes) will not be established unless specifically asked for prior to the commencement of the survey.

We will need access to the survey area(s) via an unlocked gate.

For safety reasons it is our policy not to survey or cross fields with cattle or horses in. It is assumed that all such livestock will be removed from the site prior to survey. If cattle or horses are present when accessing the site we will be unable to complete / start the survey. Charges will still apply for surveys that are cancelled or postponed or reduced in scope due to the presence of livestock.

It is assumed that a digital topographic survey or Ordnance Survey base plan will be provided in CAD format, on which the survey results will be overlain.

Capability and experience

Phase Site Investigations Ltd have been undertaking archaeological geophysical surveys since it was established in 2007. All surveys are under the direct supervision / management of Mark Whittingham, a Director at the company. Mark has a degree in geology and physics and an archaeological masters from Bradford University and has been carrying out archaeological geophysical surveys since 1997.

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Mark has previously worked for specialist archaeological and geophysical companies and has been directly involved in several hundred geophysical surveys. He has managed large-scale archaeological surveys in advance of pipelines and major developments.

Each survey team will be supervised by an experienced archaeologist / geophysicist.

All of our surveys are undertaken in accordance with set survey procedures and quality control guidelines.

Phase Site Investigations Ltd own their own magnetometers, including two Multi-sensor Array Magnetic System (MACS) which utilise arrays of magnetometers collecting high resolution, high quality data an improved survey speeds.

Phase Site Investigations Ltd have in place full professional insurance cover including Professional Indemnity (PI) cover £1 million, Public Liability cover of £5 million and Employers Liability cover of £10 million.

Deliverables

An interpretative report containing data plots and interpretation drawings will be produced (if required 2 No. copies will be provided in hardcopy format) in accordance with the specification. The report will contain the following sections:

- Summary
- Introduction - containing an overview of the survey, site description, archaeological background and scope of work
- Survey methodology – containing information on the equipment used, the site specific survey strategy, data processing and display
- Results – a general description of the types of anomaly present in the data plus details on any anomalies of interest
- Discussion and Conclusions
- Drawings
- References and bibliography (if used)
- Appendices

A summary statement on the potential limitations of a geophysical survey will be included in the report and technical information on the techniques used will be included in the Appendices.

A CD containing digital versions of the report and drawings will be attached to the report.

Data will be presented at a scale appropriate to the size of site and types of anomalies that are present in the data. Where possible data will be presented on A3 sheets with continuous blocks of data being shown on a single sheet. A greyscale plot(s) of minimally processed data will be presented with an accompanying interpretation at the same scale.

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A site location map (usually 1:50000 scale) and a more detailed plan showing the location of the entire survey area will be presented.

Greyscale plot(s) of minimally processed data will be presented with an accompanying interpretation at the same scale. The data will be displayed (clipped) at as low a range as possible (ideally -2 nT to 3 nT) to ensure that weaker anomalies have a greater chance of being identified. If the background data is strongly disturbed and a larger range will better display the data (for example -5 nT to 5 nT) then this will be stated in the report.

Several different ranges of data will be used in the interpretation to ensure that the maximum information possible is obtained from the data.

X-Y trace plots will be examined for all of the data and overlain onto the greyscale plot to assist in the interpretation, primarily to help identify dipolar responses that will probably be associated with surface / near-surface iron objects. However, X-Y trace plots will only be used in the report if they show anomalies that are not visible in the greyscale data. A digital drawing showing the X-Y trace plot overlain on the greyscale plot will be provided in the digital archive.

The survey results will also be issued as AutoCAD and pdf drawings with the technical report in pdf format.

Archiving

This quote does not allow for archiving data with an external body (such as the ADS). The costs for this can currently be prohibitive, (an additional cost of between 15% and 40% of a total survey cost) and there is still some ambiguity about what data should be archived and in what format. For these reasons we do not archive externally as standard. If external archiving is required we can do so and will charge the full cost for archiving data plus an additional 5% to cover our time.

Survey requirements and notes

- All access permissions will be arranged by the client. Access to the site and unobstructed access to the specific survey area(s) will be required for a minimum of 8 working hours per day. The survey area(s) must be available for continuous survey.
- This quote is based on a 100% sample of the survey area(s). If a price is quoted for a given area which then transpires to be a sample of a larger site then additional costs will apply.
- We will need to park our vehicle adjacent to the site for the duration of the fieldwork and will need access to the survey area via unlocked gates.
- The survey area(s) must be clear of surface obstructions, including areas of dense or high vegetation and metallic debris.
- It is assumed that a strip adjacent to metallic or brick field boundaries or other magnetic features will not be surveyed, due to the magnetic interference that such features cause. This has been allowed for in the quote and no further reduction in survey price will be offered for the associated reduction in survey area.
- The survey area(s) must be relatively level underfoot. It may not be possible to survey fields that are deep ploughed, rutted or muddy or which contain 'tussocky' vegetation. If such fields can be surveyed then for safety reasons the speed of survey may have to be reduced which could result in the survey taking longer to complete. In this instance an additional cost may apply.
- A digital copy (CAD format) of a topographical drawing of the survey area(s) or ordnance survey base plan is required prior to commencement on site, or an agreement that Phase Site Investigations Ltd will undertake a topographic survey. If Phase Site Investigations Ltd undertake a topographic survey then an additional cost may apply.
- Any amendments to the survey area or the aims of the project must be forwarded to Phase Site Investigations Ltd's office in writing. Any delay or halt to the survey due to access problems may incur additional charges for down time.
- The equipment used for the survey is robust and has been designed to work outdoors but occasionally severe weather conditions, such as snow or heavy rain, may mean that reliable results cannot be obtained and the survey may have to be postponed. Such factors are beyond the control of Phase Site Investigations Ltd but we will endeavour to keep any delays to the survey to a minimum.
- This quote allows for the production of up to two bound hardcopy reports and digital copies on CD.
- All prices are exclusive of VAT and valid for 90 days. Projects are considered confirmed upon receipt of a written instruction by an authorised person on behalf of the Client. If a project is cancelled or postponed after written confirmation has been received then any non-refundable costs that have been incurred, such as accommodation or equipment hire costs, will still be charged for. 50% of the total site works and mobilisation / demobilisation cost will be charged in the event of a confirmed project booking being cancelled within 48 hours of the agreed start date/time.
- A final invoice will be submitted when the report is presented, or as part of a payment schedule. Payment is due without discount or retention within 30 days of the date of the invoice. Interest will be charged on overdue accounts in accordance with the Late Payment of Commercial Debts (interest) Act 1998 and the Late Payment of Commercial Debts Regulations 2002. If a project fee exceeds £5,000 plus VAT or may extend over a long period of time then the agreement of a payment schedule, splitting the fee into part payments, may be required prior to commencement of the works.
- Reductions in survey area may not necessarily result in a pro rata reduction in the survey cost.

MAGNETIC SURVEYS

THEORY, SURVEY METHODOLOGY AND LIMITATIONS

Introduction

A magnetic survey is one of the geophysical techniques that Phase Site Investigations Ltd utilise to identify certain types of sub-surface features. Geophysical surveys are usually non-intrusive and involve the measurement of the geophysical properties of the sub-surface. If a feature has different physical properties to the surrounding material then it may produce a measurable variation or anomaly. Interpretation of these anomalies can allow the identification of sub-surface features. Anomalies identified by a magnetic survey are located in plan. It is not usually possible to obtain reliable depth information on the features that cause the anomalies.

The accurate interpretation of geophysical data depends on the quality of the data collected and the knowledge and experience of the project personnel. Phase Site Investigations Ltd will only use the most appropriate technology for the site specific aims and conditions and all surveys will be run by experienced staff with the work conducted as rigorously as possible. It should be noted that the identification of any sub-surface feature(s) depends on there being a measurable contrast between its physical properties and the surrounding material and so it is not possible to guarantee that all sub-surface features will be identified by a geophysical survey.

Theory

Magnetic instruments measure the value of the Earth's magnetic field; the units of which are nanoTeslas (nT). The presence of surface and sub-surface features can cause variations or anomalies in this magnetic field. The strength of the anomaly is dependent on the magnetic properties of a feature and the material that surrounds it. The two magnetic properties that are of most interest are magnetic susceptibility and thermoremnant magnetism. The former indicates the amount of ferrous (iron) minerals that are present. The latter indicates the amount of magnetism inherent in an object as a result of heating. Material that has been heated to a high temperature (fired), such as brick, can acquire strong magnetic properties and so although they may not appear to have a high iron content they can produce strong magnetic anomalies.

The magnetic survey method is highly sensitive to interference from surface and near-surface magnetic 'contaminants'. Surface features such as metallic fencing, reinforced concrete, buildings or walls all have very strong magnetic signatures that can dominate readings collected adjacent to them. Identification of anomalies caused by sub-surface features is therefore more difficult, or even impossible, in the vicinity of surface magnetic features. The presence of made ground also has a detrimental effect on the magnetic data quality as this usually contains magnetic material in the form of metallic scrap and brick. Identification of features beneath made ground is still possible if the target feature is reasonably large and has a strong magnetic response but smaller features or magnetically weak features are unlikely to be identified.

The interpretation of magnetic anomalies is often subjective and it is rarely possible to identify the cause of all magnetic anomalies. Not all features will produce a measurable magnetic response and the effectiveness of a magnetic survey is also dependant on the site-specific conditions. The main factors that may limit whether a feature can be detected are the composition of a feature, its depth and size and the surrounding material. It is not possible to guarantee that a magnetic survey will identify all sub-surface features.

Features that are commonly located using magnetic surveys include archaeological ditches and pits, buried structures or foundations, mineshafts, unexploded ordnance, metallic pipes and cables, buried piles and pile caps. The technique can also be used for geological mapping; particularly the location of igneous intrusions.

Survey methodology - Bartington

1. A magnetic survey is usually carried out on a regular 30 m grid system. Data is collected on a series of parallel traverses with a reading taken at predetermined increments along each profile. For high resolution, near-surface surveys the traverses are usually collected at 1 m spacings with readings taken at 0.25 m intervals along each traverse.

2. In ideal situations the magnetic sensors should be aligned in a north-south orientation. However, in practice the position and orientation of the survey grid is usually established parallel with the longest site boundary as this makes the setting out of survey grids and subsequent data collection easier. The sensors are then aligned either parallel or perpendicular to the baseline, whichever is closest to north-south.

3. The survey grid is established on site using a total station or a VRS RTK GNSS system. Points will be set-out to better than 0.05 m accuracy. Grid points are set-out relative to a baseline, usually at 60 m or 90 m intervals. Intermediate grid points are usually established using tape measures. Unless otherwise agreed the grid points will be marked out using bamboo canes or tent pegs which will be left in place for the duration of the field work. The survey grid is usually offset from site boundaries by several metres to reduce the detrimental effect that surface magnetic features, such as fences or walls, have on the data. Steep slopes can reduce the positional accuracy of a survey.

4. The survey grid will be tied-in using a total station or a VRS RTK GNSS system. If a total station is used the position of points on the grid are recorded relative to either existing survey stations, so that the grid can be superimposed onto an existing topographic plan, or to topographic features, such as fence and building lines. If the latter option is chosen then Phase Site Investigations Ltd will establish temporary survey stations so that the site grid can be re-established as necessary. If GNSS is used then points are recorded either direct to Ordnance Survey National Grid or to survey stations. By establishing and tying-in the grid using a total station or a VRS RTK GNSS system any anomalies identified by the magnetic survey can be located with the highest possible positional accuracy.

5. Most high resolution, near surface magnetic surveys utilise a magnetic gradiometer. A gradiometer is a hand-held instrument that consists of two magnetic sensors, one positioned directly above the other, which allows measurement of the magnetic gradient component of the magnetic field. A gradiometer configuration eliminates the need for applying corrections due to natural variations in the overall field strength that occur during the course of a day but it only measures relative variations in the local magnetic field and so comparison of absolute values between sites is not possible.

6. The Bartington Grad601-2 is a dual sensor instrument, incorporating two Grad-01-1000 gradiometers set at a distance of 1 m apart. Data is usually collected on zig-zag profiles (walking along a profile and then returning up the adjacent profile in the opposite direction) that are 2 m apart within a 30 m by 30 m grid (the dual sensor array means that this equates to 1m profile intervals).

7. Readings are taken, on either the 100 nT range (0.1 nT sensitivity) for archaeological surveys or 1000 nT range (1.0 nT sensitivity) for brownfield investigations. The instrument is balanced and ‘zeroed’ at a base station that is established on site in a magnetically quiet and uniform location. The instrument is checked for electronic and mechanical drift at this base station at regular intervals during the course of the survey.

8. The entire site will be crossed at 2 m intervals during data collection. The surveyor will also need to walk across the site when setting out grids points, establishing a base station, setting out and moving ropes and tape measures. Significant time will be spent at the base stations and the ground around these points can become quite downtrodden.

9. The data is downloaded from the instrument at the end of each days survey, usually using bespoke software specific to that instrument. The data is then imported into a gridding and interpolation software package, such as Archaeosurveyor (DW consulting) or Surfer (Golden Software). Magnetic data rarely requires detailed processing although filtering can be applied in some cases to reduce background noise or enhance weaker anomalies. The processing steps that are used will be detailed in the technical report

10. A plot of the data will be exported from the gridding software, usually in bitmap or jpeg format. This will be imported into AutoCAD where it will be displayed relative to the available map detail. An interpretation of the anomalies identified in the magnetic data will be presented in AutoCAD and an accompanying technical report will also be produced. The report and drawings can be provided in both hardcopy and digital formats.

Survey methodology - MACS

1. The multi-sensor cart system (MACS) utilises between 4 and 8 Foerster 4.032 Ferex CON 650 gradiometers with a control unit and data logger.

2. The gradiometers are carried on a non-magnetic cart and have a spacing of either 0.5 m or 1 m. Readings are taken at between 0.05 and 0.25 intervals, depending on the speed that the cart is pulled at.

3. The orientation of the sensors does not have an impact on data quality and the sensors do not have to be balanced during the course of the survey. An arbitrary zero value for the sensors is set at the commencement of the survey and the control unit corrects each sensor so that the data is averaged about a mean value.

4. The MACS utilises an RTK GNSS system which means that survey grids do not have to be established. Instead an area is surveyed over a series of continuous profiles and the position of each data point is recorded using an RTK GNSS system.

5. Data is collected on zig-zag profiles along the full length or width of a field, although fields can be sub-divided if they are particularly large. Marker canes are set-out along field boundaries at set intervals and these are used to align the profiles. The survey profiles are usually offset from field boundaries, buildings and other metallic features several metres to reduce the detrimental effect that these surface magnetic features have on the data.

6. Data can be recorded direct to Ordnance Survey National Grid co-ordinates or to a local grid. Temporary survey stations (wooden stakes) will be left on site to allow the survey grid to be re-established if required.

7. The Foerster gradiometers have a resolution of 0.2 nT but the stability of the cart system significantly reduces noise caused by instrument tilt and movement when compared with a traditional hand-held gradiometer system and the increased data intervals provide a higher resolution data set. The sensors have a range of ± 10,000nT.

8. An all terrain vehicle (ATV) can be utilised to tow the MACS. Please ensure that the land owner / tenant farmer is happy for an ATV to be used as we do not accept any liability for potential damage caused by our survey equipment or ATV.

9. The data is downloaded from the instrument at the end of each days survey, usually using bespoke software specific to that instrument. The data is then imported into a gridding and interpolation software package, such as Archaeosurveyor (DW consulting) or Surfer (Golden Software). Magnetic data rarely requires detailed processing although filtering can be applied in some cases to reduce background noise or enhance weaker anomalies. The processing steps that are used will be detailed in the technical report.

10. A plot of the data will be exported from the gridding software, usually in bitmap or jpeg format. This will be imported into AutoCAD where it will be displayed relative to the available map detail. An interpretation of the anomalies identified in the magnetic data will be presented in AutoCAD and an accompanying technical report will also be produced. The report and drawings can be provided in both hardcopy and digital formats.

Limitations and exclusions

A. A magnetic survey method requires the operator to walk over the site at a constant walking pace whilst holding or towing the instrument. The presence of an uneven ground surface, dense, high or mature vegetation or surface obstructions may mean that some areas cannot be surveyed.

B. The depth at which features can be detected will vary depending on their composition, size, the surrounding material and the type of magnetometer used for the survey. In good conditions large, magnetic targets, such as buried drums or tanks can be located at depths of more than 4 m. Smaller targets, such as buried foundations or archaeological features can be located at depths of between 1 m and 2 m.

C. A magnetic survey is highly sensitive to interference from surface and near-surface magnetic 'contaminants'. Surface features such as metallic fencing, reinforced concrete, buildings or walls all have very strong magnetic signatures that can dominate readings collected adjacent to them. Identification of anomalies caused by sub-surface features is therefore more difficult or even not possible in the vicinity of surface and near-surface magnetic features.

D. The presence of made ground also has a detrimental effect on the magnetic data quality as this usually contains magnetic material in the form of metallic scrap and brick. Identification of features beneath made ground is still possible if the target feature is reasonably large and has a strong magnetic response but smaller features or magnetically weak features are unlikely to be identified.

E. A magnetic survey does not directly locate sub-surface features - it identifies variations or anomalies in the local magnetic field caused by features. It can be possible to interpret the cause of anomalies based on the size, shape and strength of response but it should be recognised that a magnetic survey produces a plan of magnetic variations and not a plan of all sub-surface features. Interpretation of the anomalies is often subjective and it is rarely possible to identify the cause of all magnetic anomalies. Geological or pedological (soil) variations or features can produce responses similar to those caused by man-made (anthropogenic) features.

F. Anomalies identified by a magnetic survey are located in plan. It is not usually possible to obtain reliable depth information on the features that cause the anomalies.

G. Not all features will produce a measurable magnetic response and the effectiveness of a magnetic survey is also dependant on the site-specific conditions. It is not possible to guarantee that a magnetic survey will identify all sub-surface features. A magnetic survey is often most-effective at identifying sub-surface features when used in conjunction with other complementary geophysical techniques.