GEOPHYSICAL SURVEY REPORT

STRATASCAN™

SUMO Group Member

Project name:

Upper Pond, Petworth

Client:

Archaeology South East

April 2015

Job ref:

J7869

Report author:

Rebecca Davies BSc (Hons)

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Field team:

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Techniques:

Detailed magnetic survey – Gradiometry
Electromagnetic survey – EM31
Resistance – Resistivity Imaging Lines

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Survey date:

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1 SUMMARY OF RESULTS

Detailed gradiometry, electromagnetic and resistance surveys were conducted over approximately 4.4 hectares of grassland. A possible land drain and pipe have been identified in the Arbour Hill and North Edge Water Supply areas, however there is no further evidence of land drains associated with the pond. Very weak linear trends have been identified but their cause is unclear. A number of features have been identified that are likely to relate to the Tillington Tunnel, with possible adjacent structural features identified. Further anomalies may be related to the tunnel and associated drainage system, though this cannot be determined with any degree of confidence. The remaining features are modern in origin and include evidence of modern agriculture, a track way, scattered magnetic debris, disturbance from nearby ferrous objects such as fences and magnetic spikes that are likely to be modern rubbish.

2 INTRODUCTION

2.1 *Background synopsis*

Stratascan were commissioned to undertake a geophysical survey of an area in order to identify land drains and a tunnel associated with the Upper Pond at Petworth. This survey forms part of an archaeological investigation being undertaken by Archaeology South East. The aim of the wider project is to desilt and repair the water management system to safeguard its long term survival.

2.2 *Site location*

The site is located at OS ref. SU 972 221, adjacent to Upper Pond at Petworth House, West Sussex.

2.3 *Description of site*

The survey area is approximately 6 hectares of undulating grassland. An area of around 1.4 hectares was not surveyed to due areas of overgrown vegetation and woodland.

2.4 *Geology and soils*

The underlying geology across the centre of the site is mudstone of Atherfield Clay Formation with areas of Hythe Formation – sandstone, in the eastern and western edges of the survey area (British Geological Survey website). No drift geology is recorded for the area (British Geological Survey website).

The overlying soils across the majority of the site are known as Fyfield 2, which are typical argillic brown earths, with an area in the extreme north of the site overlain by Wickham 5 soils which are typical stagnogleyic soils. Fyfield 2 soils consist of well drained coarse loamy and sandy soils over sands and sandstones while Wickham 5 soils consist of slowly permeable seasonally waterlogged fine loamy over clayey, fine silty over clayey and clayey soils (Soil Survey of England and Wales, Sheet 6 South East England).

Due to the extensive landscaping of Petworth Park over many centuries it is likely that material from elsewhere has been brought in, therefore altering the natural ground conditions.

2.5 *Site history and archaeological potential*

Extract from "Brief to consultants for archaeological surveys at the Upper Pond, Petworth Park, West Sussex" (Natural England, 2014):

"Petworth Park has been the scene of over 400 years of developing park landscape which has incorporated early 17th century parkland features such as warrens and canals, through to grander designs notably by Capability Brown in 1751 and Anthony Salvin after 1869…

..The convoluted systems of drains and culverts that supply the Upper Pond with water are only partially understood and a series of collapses has suggested that some of the drains are in need of urgent repair. In order to secure an ongoing water supply for the pond we require a better understanding of the system and an assessment of the blockages and risks so as to be able to work up a programme of targeted and effective repairs.

The 'Arbour Hill', 'Lawn Hill' and 'North Edge' drainage areas are believed to comprise relatively shallow brick built or clay pipe drains, while the 'Tillington' drainage route comprises a much more complex series of tunnels, cisterns and sluices at up to 3 or more metres depth."

2.6 *Survey objectives*

The objective of the survey was to locate any drains or culverts associated with the pond in order to identify collapses and blockages within the drainage system prior to the development of a repair programme.

2.7 *Survey methods*

This report and all fieldwork have been conducted in accordance with both the English Heritage guidelines outlined in the document: *Geophysical Survey in Archaeological Field Evaluation, 2008* and with the Institute for Archaeologists document *Standard and Guidance for Archaeological Geophysical Survey.*

A combination of detailed magnetic survey (gradiometry), ground penetrating radar, electromagnetic survey and resistivity imaging lines were used as an efficient and effective method of locating possible land drains and tunnels. Gradiometer survey and ground penetrating radar were used across the Arbour Hill, Lawn Hill and North Edge areas while the electromagnetic survey and subsequent resistivity imaging lines were placed at intervals along the Tillington drainage route. More information regarding these techniques is included in Appendix A.

2.8 Processing, presentation and interpretation of results

2.8.1 Gradiometry

Processing is performed using specialist software. This can emphasise various aspects contained within the data but which are often not easily seen in the raw data. Basic processing of the magnetic data involves 'flattening' the background levels with respect to adjacent traverses and adjacent grids. Once the basic processing has flattened the background it is then possible to carry out further processing which may include low pass filtering to reduce 'noise' in the data and hence emphasise the archaeological or man-made anomalies.

The following schedule shows the basic processing carried out on all minimally processed gradiometer data used in this report:

1. *Destripe* (Removes striping effects caused by zero-point discrepancies between different sensors and walking directions)

2. *Destagger* (Removes zigzag effects caused by inconsistent walking speeds on sloping, uneven or overgrown terrain)

The presentation of the data for each site involves a print-out of the minimally processed data both as a greyscale plot and a colour plot showing extreme magnetic values. Magnetic anomalies have been identified and plotted onto the 'Abstraction and Interpretation of Anomalies' drawing for the site.

2.8.2 Electromagnetic

During collection data is stored on a field computer using NAV31 software. The raw data files are then converted into xyz format using TrackMaker31 software.

Positioning information is recorded during the survey using a Trimble Differential antenna and logged as angular latitude/longitude coordinates. These are converted to OS projected coordinates using GridInquest6.

Surfer8 is then used to interpolate the data into a 0.5x0.5m grid allowing presentation of the results as a colour plot.

2.8.3 Resistivity imaging

RES2DINV software is used to process resistivity imaging data. The smoothness-constrained Gauss-Newton least-squares method inversion technique is used to produce a 2D model of the subsurface from the apparent resistivity data. The 2D model illustrates the changes in subsurface resistivity, represented by a standard colour scale.

3 RESULTS

Gradiometry

The detailed magnetic gradiometer survey conducted at Petworth House has identified a small number of anomalies that have been characterised as being of *possible* archaeological origin along with possible drains and services.

The difference between *probable* and *possible* archaeological origin is a confidence rating. Features identified within the dataset that form recognisable archaeological patterns or seem to be related to a deliberate historical act have been interpreted as being of a probable archaeological origin.

Features of possible archaeological origin tend to be more amorphous anomalies which may have similar magnetic attributes in terms of strength or polarity but are difficult to classify as being archaeological or natural.

The following list of numbered anomalies refers to numerical labels on the interpretation plots.

3.1 *Probable Archaeology*

No probable archaeology has been identified within the survey area.

3.2 *Possible Archaeology*

1 Small, discrete positive anomalies in the east of the site. These are indicative of former cut features of possible archaeological origin, likely to be related the park landscaping

2 A weak bipolar linear anomaly in the north of the site is possibly related to a land drain.

3.3 Other Anomalies

3 Strong, bipolar linear anomaly in the south of the site, likely to be related to an underground service such as a pipe. This may be of modern origin, however it may also be related to an historic metal pipe associated with the pond.

4 Areas of weak scattered magnetic debris in the centre of the site. These are likely to be modern in origin.

5 Linear trends in the north and east of the site. These are of unknown origin. They are unlikely to be related to land drains, but this cannot be totally ruled out.

6 Areas of magnetic disturbance are the result of substantial nearby ferrous metal objects such as fences and underground services. These effects can mask weaker archaeological anomalies, but on this site have not affected a significant proportion of the area.

7 A number of magnetic 'spikes' (strong focussed values with associated antipolar response) indicate ferrous metal objects. These are likely to be modern rubbish.

Electromagnetic

The detailed electromagnetic survey conducted at Petworth House has identified a small number of anomalies. These are listed in the table below.

A An area of enhanced response related to a trackway visible on aerial photography.

B An area of enhanced response in the west of the survey area. This is a result of nearby ferrous objects such as fences.

C Areas of enhanced response in the east of the survey area are of probable modern origin however their exact origin is unknown.

Resistivity Imaging Lines

The resistivity imaging survey has identified two features of high resistance in Lines 1 & 2 that are likely to be related to the 'Tillington' drainage route. Line 3 does not show such convincing anomalies and it is possible that the tunnel route bypasses Line 3 and appears again in the south of Line 4. Line 3 does show some moderately high resistance anomalies which may relate to structural features though this cannot be determined with any degree of confidence. High resistance anomalies in Line 4 suggest that there may be a series of four, possibly five adjacent structures. Similarly Line 2 shows one stronger response within an overall elevated high resistance lens which could indicate a series of structures.

Ground Penetrating Radar

A trial of ground penetrating radar was carried out over a number of selected areas. The traverses did not identify any features that could be related to the system of drains or culverts surrounding the pond and it was decided not to pursue this technique further.

4 CONCLUSION

The gradiometer survey at Upper Pond, Petworth has identified a small number of features that may be related to land drains and pipes associated with the pond, however there is no strong evidence of an associated drainage system in either the gradiometer data or trial radar traverses. Weak linear features may possibly be related to drains, though these are more likely to relate to agricultural activity or landscaping features of the park. It may be that the local ground conditions have been unresponsive to the techniques used, or that the features are not substantial enough to be detected.

The electromagnetic survey across the Tillington water supply area did not provide any evidence of a complex system of tunnels, cisterns and sluices. The subsequent resistivity imaging lines have identified several features that are likely to relate to the underground drainage system. Given the complex nature of the drainage route and that the system comprises a number of cisterns, tunnels and sluices it is possible that the other high resistance anomalies that have been identified may be related to the tunnel system. The anomalies identified in Lines 2 and 4 may be related to a series of adjacent structural features. Many of the anomalies identified through the resistivity imaging survey are at a consistent depth, which also indicates they are likely to be caused by the same buried feature.

5 REFERENCES

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APPENDIX A – METHODOLOGY & SURVEY EQUIPMENT

Gradiometry

Grid locations

The location of the survey grids has been plotted together with the referencing information. Grids were set out using a Leica 705auto Total Station and referenced to suitable topographic features around the perimeter of the site or a Leica Smart Rover RTK GPS.

An RTK GPS (Real-time Kinematic Global Positioning System) can locate a point on the ground to a far greater accuracy than a standard GPS unit. A standard GPS suffers from errors created by satellite orbit errors, clock errors and atmospheric interference, resulting in an accuracy of 5m-10m. An RTK system uses a single base station receiver and a number of mobile units. The base station re-broadcasts the phase of the carrier it measured, and the mobile units compare their own phase measurements with those they received from the base station. A SmartNet RTK GPS uses Ordnance Survey's network of over 100 fixed base stations to give an accuracy of around 0.01m.

Survey equipment and gradiometer configuration

Although the changes in the magnetic field resulting from differing features in the soil are usually weak, changes as small as 0.2 nanoTeslas (nT) in an overall field strength of 48,000nT, can be accurately detected using an appropriate instrument.

The mapping of the anomaly in a systematic manner will allow an estimate of the type of material present beneath the surface. Strong magnetic anomalies will be generated by buried iron-based objects or by kilns or hearths. More subtle anomalies such as pits and ditches can be seen if they contain more humic material which is normally rich in magnetic iron oxides when compared with the subsoil.

To illustrate this point, the cutting and subsequent silting or backfilling of a ditch may result in a larger volume of weakly magnetic material being accumulated in the trench compared to the undisturbed subsoil. A weak magnetic anomaly should therefore appear in plan along the line of the ditch.

The magnetic survey was carried out using a dual sensor Grad601-2 Magnetic Gradiometer manufactured by Bartington Instruments Ltd. The instrument consists of two fluxgates very accurately aligned to nullify the effects of the Earth's magnetic field. Readings relate to the difference in localised magnetic anomalies compared with the general magnetic background. The Grad601-2 consists of two high stability fluxgate gradiometers suspended on a single frame. Each gradiometer has a 1m separation between the sensing elements so enhancing the response to weak anomalies.

Sampling interval

Readings were taken at 0.25m centres along traverses 1m apart. This equates to 3600 sampling points in a full 30m x 30m grid.

Depth of scan and resolution

The Grad 601-2 has a typical depth of penetration of 0.5m to 1.0m, though strongly magnetic objects may be visible at greater depths. The collection of data at 0.25m centres provides an optimum methodology for the task balancing cost and time with resolution.

Data capture

The readings are logged consecutively into the data logger which in turn is daily down- loaded into a portable computer whilst on site. At the end of each site survey, data is transferred to the office for processing and presentation.

Electromagnetic

Positioning

Data were collected on a continuous mode along parallel traverses. Positioning information were automatically recorded using an external differential GPS antenna (Trimble ProXT). There was no obstruction on site, providing an open sky, resulting in good condition for the use of GPS tracking allowing precisions of 1m.

Survey equipment and gradiometer configuration

The Geonics EM31 uses induced current to generate a response from the sub-surface. A small loop antenna at one end of a 3.66m boom transmits a primary magnetic field. This primary field interacts with the ground and induces electric currents to flow in the ground. Those are known as Eddy currents. The Eddy currents in turn generate a secondary magnetic field. A resulting magnetic field is measured by a small receiver loop at the opposite end of the boom and some internal circuitry separates the primary and secondary field.

The secondary field is composed of an inphase and a quadrature component. The inphase response is related to magnetic susceptibility and is essentially the same as that from a metal detector; it is expressed as units of parts per thousand of the primary transmitted field. The quadrature response measures the bulk electrical properties of the site, expressed as an apparent electrical conductivity in milliSiemens per metre (mS/m).

Sampling interval

Readings were collected continuously each 0.25m along traverses approximately 2m apart. The EM31 was positioned in vertical mode with the boom along the survey line. Both the inphase ("related to the magnetic susceptibility") and quadrature (“ground conductivity”) components have been recorded.

Depth of scan and resolution

The depth of scan for the vertical dipole is approximately 3 to 6m. The resolution is approximately a fifth of the coil separation thus giving 0.7m.

Resistivity Imaging

Positioning

A Trimble R8 GPS antenna was used to set out the survey lines 95.25m in length.

An RTK GPS (Real-time Kinematic Global Positioning System) can locate a point on the ground to a far greater accuracy than a standard GPS unit. A standard GPS suffers from errors created by satellite orbit errors, clock errors and atmospheric interference, resulting in an accuracy of 5m-10m. An RTK system uses a single base station receiver and a number of mobile units. The base station re-broadcasts the phase of the carrier it measured, and the mobile units compare their own phase measurements with those they received from the base station. A SmartNet RTK GPS uses Ordnance Survey’s network of over 100 fixed base stations to give an accuracy of around 0.01m.

Survey equipment and configuration
128 electrodes were connected to a Tigre 128 resistivity meter. The Wenner α electrode array uses four equally spaced electrodes. Current is induced through the outer electrodes and potential is measured between the inner electrodes. Multiple combinations of electrodes are used along the length of the survey line to achieve readings to a desirable depth.

Sampling interval, depth and resolution
128 electrodes are spaced at intervals of 0.75m along the length of the survey line. A total of 2378 readings were recorded up to a depth of approximately 11m.

APPENDIX B – BASIC PRINCIPLES OF MAGNETIC SURVEY

Detailed magnetic survey can be used to effectively define areas of past human activity by mapping spatial variation and contrast in the magnetic properties of soil, subsoil and bedrock.

Weakly magnetic iron minerals are always present within the soil and areas of enhancement relate to increases in *magnetic susceptibility* and permanently magnetised *thermoremanent* material.

Magnetic susceptibility relates to the induced magnetism of a material when in the presence of a magnetic field. This magnetism can be considered as effectively permanent as it exists within the Earth's magnetic field. Magnetic susceptibility can become enhanced due to burning and complex biological or fermentation processes.

Thermoremanence is a permanent magnetism acquired by iron minerals that, after heating to a specific temperature known as the Curie Point, are effectively demagnetised followed by re-magnetisation by the Earth's magnetic field on cooling. Thermoremanent archaeological features can include hearths and kilns and material such as brick and tile may be magnetised through the same process.

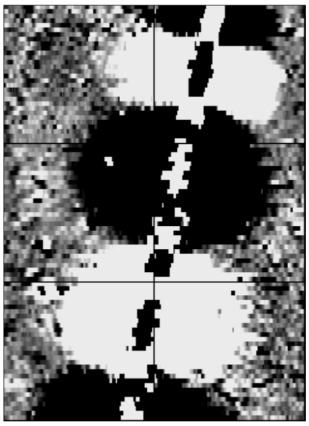
Silting and deliberate infilling of ditches and pits with magnetically enhanced soil creates a relative contrast against the much lower levels of magnetism within the subsoil into which the feature is cut. Systematic mapping of magnetic anomalies will produce linear and discrete areas of enhancement allowing assessment and characterisation of subsurface features. Material such as subsoil and non-magnetic bedrock used to create former earthworks and walls may be mapped as areas of lower enhancement compared to surrounding soils.

Magnetic survey is carried out using a fluxgate gradiometer which is a passive instrument consisting of two sensors mounted vertically 1m apart. The instrument is carried about 30cm above the ground surface and the top sensor measures the Earth's magnetic field whilst the lower sensor measures the same field but is also more affected by any localised buried field. The difference between the two sensors will relate to the strength of a magnetic field created by a buried feature, if no field is present the difference will be close to zero as the magnetic field measured by both sensors will be the same.

Factors affecting the magnetic survey may include soil type, local geology, previous human activity, disturbance from modern services etc.

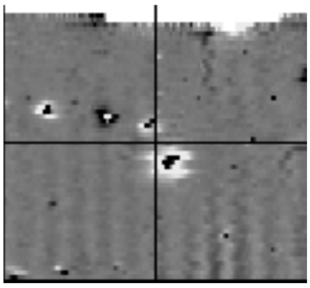
APPENDIX C – GLOSSARY OF MAGNETIC ANOMALIES

Bipolar



A bipolar anomaly is one that is composed of both a positive response and a negative response. It can be made up of any number of positive responses and negative responses. For example a pipeline consisting of alternating positive and negative anomalies is said to be bipolar. See also dipolar which has only one area of each polarity. The interpretation of the anomaly will depend on the magnitude of the magnetic field strength. A weak response may be caused by a clay field drain while a strong response will probably be caused by a metallic service.

Dipolar

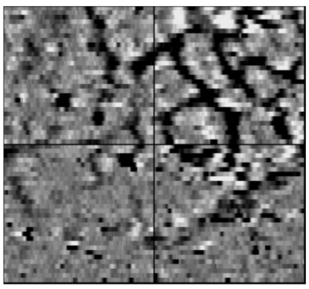


This consists of a single positive anomaly with an associated negative response. There should be no separation between the two polarities of response. These responses will be created by a single feature. The interpretation of the anomaly will depend on the magnitude of the magnetic measurements. A very strong anomaly is likely to be caused by a ferrous object.

Positive anomaly with associated negative response

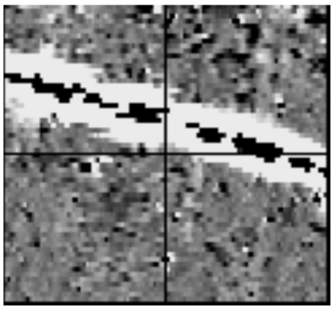
See bipolar and dipolar.

Positive linear



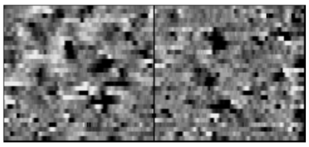
A linear response which is entirely positive in polarity. These are usually related to in-filled cut features where the fill material is magnetically enhanced compared to the surrounding matrix. They can be caused by ditches of an archaeological origin, but also former field boundaries, ploughing activity and some may even have a natural origin.

Positive linear anomaly with associated negative response



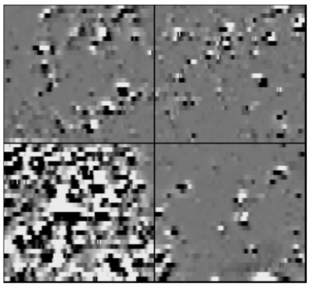
A positive linear anomaly which has a negative anomaly located adjacently. This will be caused by a single feature. In the example shown this is likely to be a single length of wire/cable probably relating to a modern service. Magnetically weaker responses may relate to earthwork style features and field boundaries.

Positive point/area



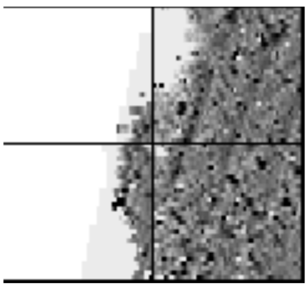
These are generally spatially small responses, perhaps covering just 3 or 4 reading nodes. They are entirely positive in polarity. Similar to positive linear anomalies they are generally caused by in-filled cut features. These include pits of an archaeological origin, possible tree bowls or other naturally occurring depressions in the ground.

Magnetic debris



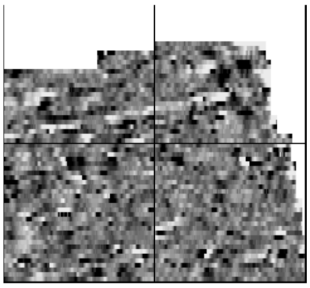
Magnetic debris consists of numerous dipolar responses spread over an area. If the amplitude of response is low (+/-3nT) then the origin is likely to represent general ground disturbance with no clear cause, it may be related to something as simple as an area of dug or mixed earth. A stronger anomaly (+/-250nT) is more indicative of a spread of ferrous debris. Moderately strong anomalies may be the result of a spread of thermoremanent material such as bricks or ash.

Magnetic disturbance



Magnetic disturbance is high amplitude and can be composed of either a bipolar anomaly, or a single polarity response. It is essentially associated with magnetic interference from modern ferrous structures such as fencing, vehicles or buildings, and as a result is commonly found around the perimeter of a site near to boundary fences.

Negative linear

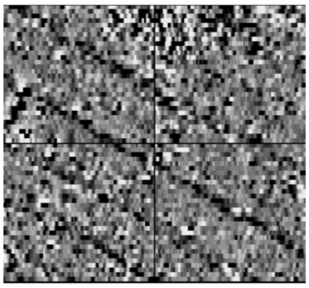


A linear response which is entirely negative in polarity. These are generally caused by earthen banks where material with a lower magnetic magnitude relative to the background top soil is built up. See also ploughing activity.

Negative point/area

Opposite to positive point anomalies these responses may be caused by raised areas or earthen banks. These could be of an archaeological origin or may have a natural origin.

Ploughing activity



Ploughing activity can often be visualised by a series of parallel linear anomalies. These can be of either positive polarity or negative polarity depending on site specifics. It can be difficult to distinguish between ancient ploughing and more modern ploughing. Clues such as the separation of each linear, straightness, strength of response and cross cutting relationships can be used to aid this, although none of these can be guaranteed to differentiate between different phases of activity.

Polarity

Term used to describe the measurement of the magnetic response. An anomaly can have a positive polarity (values above 0nT) and/or a negative polarity (values below 0nT).

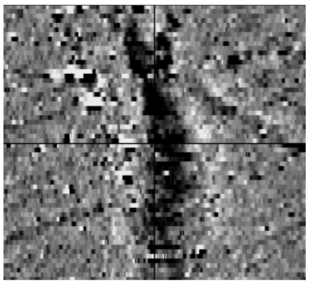
Strength of response

The amplitude of a magnetic response is an important factor in assigning an interpretation to a particular anomaly. For example a positive anomaly covering a 10m^2 area may have values up to around 3000nT, in which case it is likely to be caused by modern magnetic interference. However, the same size and shaped anomaly but with values up to only 4nT may have a natural origin. Colour plots are used to show the amplitude of response.

Thermoremanent response

A feature which has been subject to heat may result in it acquiring a magnetic field. This can be anything up to approximately +/-100 nT in value. These features include clay fired drains, brick, bonfires, kilns, hearths and even pottery. If the heat application has occurred in situ (e.g. a kiln) then the response is likely to be bipolar compared to if the heated objects have been disturbed and moved relative to each other, in which case they are more likely to take an irregular form and may display a debris style response (e.g. ash).

Weak background variations



Weakly magnetic wide scale variations within the data can sometimes be seen within sites. These usually have no specific structure but can often appear curvy and sinuous in form. They are likely to be the result of natural features, such as soil creep, dried up (or seasonal) streams. They can also be caused by changes in the underlying geology or soil type which may contain unpredictable distributions of magnetic minerals, and are usually apparent in several locations across a site.

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