SUFFOLK ARCHAEOLOGY

• A HISTORY OF EXPERTISE •

Bungay Castle

Bungay, Suffolk

Client:
Olly Barnes, Bungay Castle Trust

Date:
September 2017

BUN 004
Geophysical Surveys Report
SACIC Report No. 2017/078
Author: Timothy Schofield HND BSc MCIfA

Bungay Castle, Bungay, Suffolk
BUN 004

Geophysical Survey Report

SACIC Report No. 2017/078

Author: Timothy Schofield

Illustrator: Timothy Schofield

Editor: Stuart Boulter

Report Date: September 2017

HER Information

Site Code:	**BUN 004**
Event Number:	**ESF 25629**
Site Name:	**Bungay Castle, Bungay, Suffolk**
Report Number	**2017/078**
Planning Application No:	**n/a**
Date of Fieldwork:	**July 13th – 16th Aug 2017**
Grid Reference:	**TL 3350 8973**
Oasis Reference:	**290477**
Curatorial Officer:	**Nick Carter, Will Fletcher, Historic England**
Project Officer:	**Timothy Schofield**
Client/Funding Body:	**Olly Barnes, Bungay Castle Trust**
Client Reference:	**n/a**

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http://ads.ahds.ac.uk/catalogue/library/greylit

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Any opinions expressed in this report about the need for further archaeological work are those of Suffolk Archaeology CIC. Ultimately the need for further work will be determined by the Local Planning Authority and its Archaeological Advisors when a planning application is registered. Suffolk Archaeology CIC cannot accept responsibility for inconvenience caused to the clients should the Planning Authority take a different view to that expressed in the report.

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Date:	September 2017

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Position:	Director
Date:	September 2017
Signed:	R.V.Gardner.

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Summary

In July and August 2017 Suffolk Archaeology Community Interest Company (SACIC) undertook detailed geophysical surveys within the bailey of Bungay Castle, Bungay, Suffolk. Three techniques were requested by Historic England to be deployed over the 0.24hectare grass covered bailey, comprising fluxgate gradiometer, earth resistance meter and ground penetrating radar surveys.

The three instruments highlighted a narrow range of geophysical anomalies that have significant archaeological potential, including in-situ structural remains that may include walls, floors and a potential well. Anomalies indicative of robbed-out or service trench runs, rubbish pits or geological deposits, demolition or levelling deposits and an extant Tarmacadam drive were further prospected.

1. Introduction

In July and August 2017, detailed geophysical surveys covering an area of 0.24 hectares within the bailey of the scheduled monument of Bungay Castle (National Heritage List for England Ref. 1006060), Bungay, Suffolk (Fig.1) were undertaken by Suffolk Archaeology Community Interest Company (SACIC).

The detailed geophysical surveys were requested by Historic England, to identify areas of high archaeological potential. Suffolk Archaeology CIC were commissioned to undertake the project by Olly Barnes of the Bungay Castle Trust.

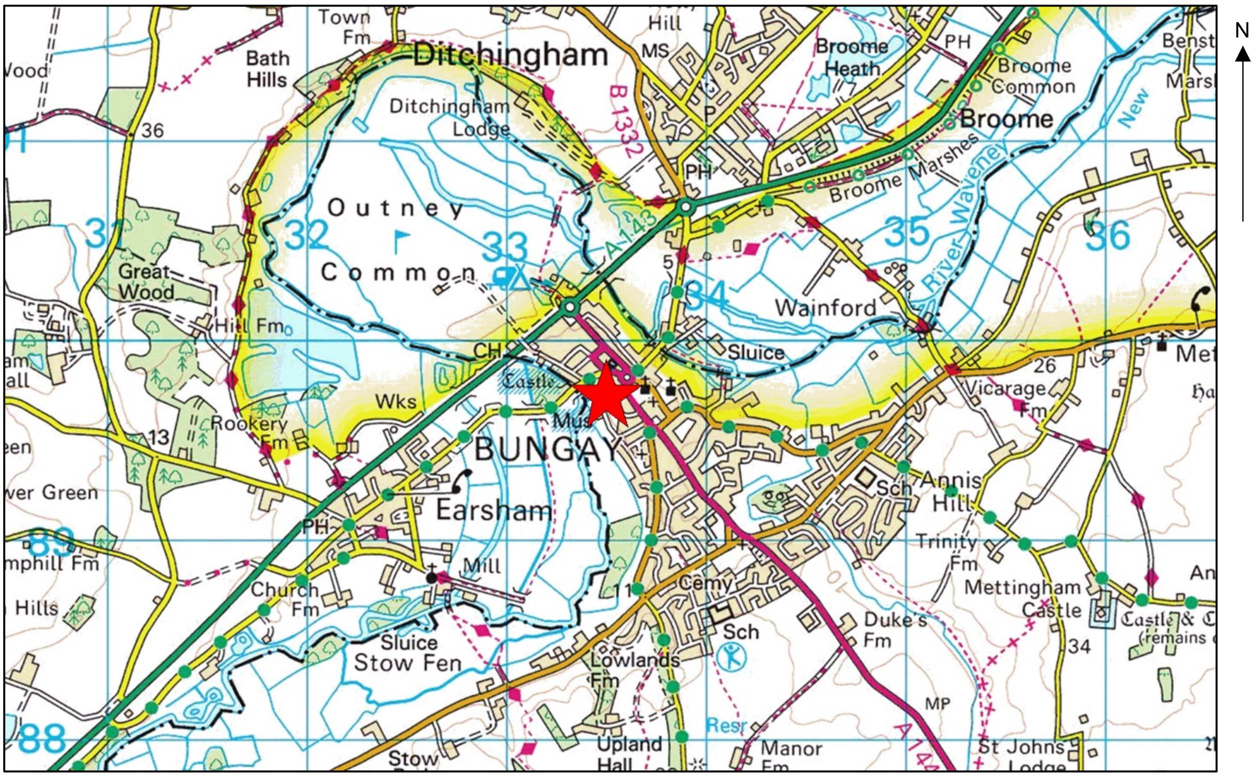

Figure 1. Location map

0 2km

2. Geology and topography

The geophysical survey area lies within the bailey of the Scheduled Monument of Bungay Castle (National Heritage List for England Ref. 1006060). The survey was undertaken at the request of Nick Carter and Will Fletcher of Historic England, who provided the Section 42 Licence.

Superficial geology is described as sand and gravel river terrace deposits, overlying a sedimentary bedrock of Crag Group sands (British Geological Survey, 2017). The site is broadly flat and is located at a height of *c.* 10m above Ordnance Datum.

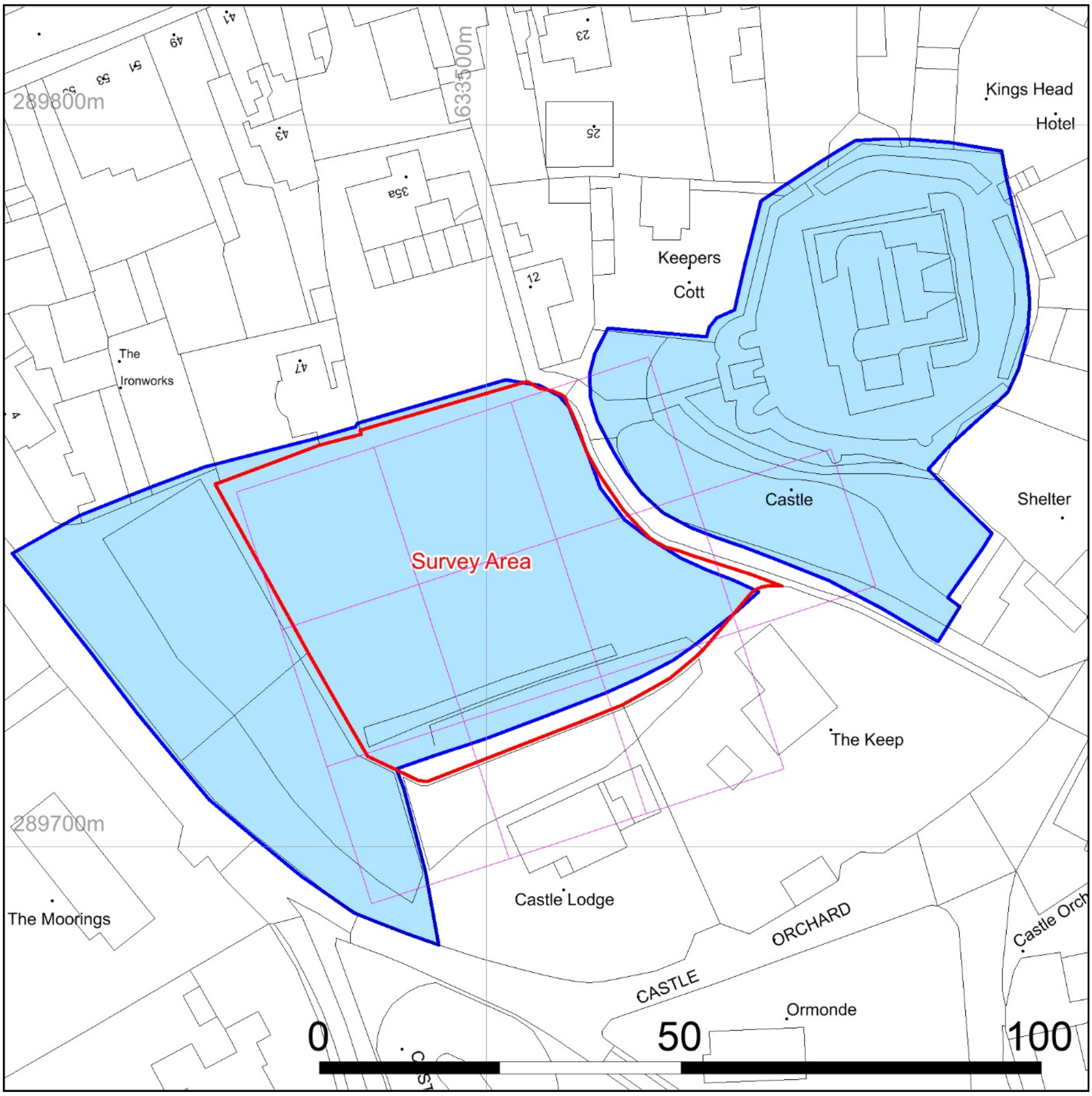

Figure 2. Survey area (red) and grid location (purple) in relation to the Scheduled Monument (blue)

3. Archaeology and historical background

Bungay Castle was originally built in 1100 by Roger Bigod, a Norman invader who assisted King William in conquering England in 1066, he was rewarded for his loyalty by being given a large area of East Anglia. In around 1165, his second son Hugh Bigod added a stone keep that had 5 - 7m thick walls and stood to a height of 33m. This version of the castle was destroyed in 1174 during a revolt. Hugh Bigod died in 1178 and the castle remained uninhabited until 1269, when Roger Bigod inherited the title, built the gate towers and renovated the castle, he died shortly after the castle was completed in 1297 and the castle fell into disrepair.

In 1934 Dr Leonard Cane started a programme of excavation and repair, revealing many features that were hidden. The Duke of Norfolk presented the castle to the town in 1987 with an endowment to help towards its preservation; today it is owned and administered by the Bungay Castle Trust.

A geophysical survey employing an earth resistance meter and a fluxgate gradiometer was undertaken on the bailey by Geophysical Surveys of Bradford in 1990 (Gaffney and Gater, 1990). Subtle anomalies were noted by the authors that included a wall and made ground layers; however, their archaeological significance could not be determined.

4. Methodology

Instrument types

Three different instruments were used to undertake the geophysical survey. A Bartington DualGrad 601-2 fluxgate gradiometer, a Geoscan Research RM85 advanced earth resistance meter and an Utsi Electronics TriVue ground penetrating radar. The weather for the magnetometer survey was sunny, however during the radar and resistance meter surveys there were large downpours causing a degree of moist soil conditions, despite this inclement weather the ground conditions were found to be suitable.

Survey grid layout

The detailed fluxgate gradiometer and earth resistance meter surveys were undertaken on the same 20m grid (Fig. 3, blue grid), orientated east to west and geolocated employing a Leica Viva GS08+ Smart Rover RTK GLONASS/GPS, allowing an accuracy of +/- 0.03m. Data were converted to National Grid Transformation OSTN15. The ground penetrating radar survey was undertaken along traverses that are also illustrated in Figure 3 (cyan lines).

Survey grid restoration

Three virtual survey grid stations were placed on survey grid nodes along the baselines of the survey grid, this will allow both the grid and the anomalies to be accurately relocated (Fig. 3).

Bartington DualGrad 601-2

The first instrument to be deployed over the bailey was the Bartington DualGrad 601-2, the magnetic background was found to be very high during the initial site scan, therefore it was decided to calibrate the instrument in the meadow further down slope from the survey area.

Instrument calibration and settings

One hour was allocated to allow the instruments' sensors to reach optimum operating temperature before the survey commenced. Instrument sampling intervals were set to 0.125m along 1m traverses (eight readings per metre).

Data capture

Detailed fluxgate gradiometer survey data points were recorded on an internal data logger that were downloaded and checked for quality at midday and in the evening, allowing grids to be re-surveyed if necessary. A pro-forma survey sheet was completed to allow data composites to be created. Data were filed in unique project folders and backed-up onto an external storage device and then a remote server in the evening.

Data software, processing and presentation

The site had a high magnetic signature, however the strong anomalies contrasted well with this increased magnetic background allowing good quality raw survey data to be collected, which required minimal data processing. Datasets were composited and processed using DW Consulting's Terrasurveyor v.3.0.32.4; raw grid files, composites and raster graphic plots will be stored and archived in this format. Minimal processing algorithms were undertaken on the raw (Fig. 4 and processed datasets (Figs. 5 - 6); schedules are presented in Appendix 1.

Data composites were exported as raster images into AutoCAD. An interpretation plan based on the combined results of the raw, processed and xy trace plots (Figs. 4 - 6) has been produced (Fig. 7).

Geoscan Research RM85 Advanced

The earth resistance meter survey was undertaken along the same grid as the fluxgate gradiometer survey with only the Tarmacadam road being unsuitable for survey. Sampling intervals were set to 0.5m along 0.5m traverses.

Instrument calibration and settings

A three-parallel twin (six probe pole-pole) array was employed, gain was set to 10, frequency was 122.5Hz with an output voltage of 45v, the auto-log delay was 300ms and the high-pass filter was 0hz. Station readings were equalised when the remote probes were moved to allow consistent data matching between the survey grids.

Data capture

Detailed earth resistance meter data points were recorded on an internal data logger that were downloaded and checked for quality at midday and in the evening, allowing grids to be re-surveyed if required. A pro-forma survey sheet was completed to allow data composites to be created. Data were filed in unique project folders and backed-up onto an external storage device and then a remote server in the evening.

Data software, processing and presentation

The ground conditions for the earth resistance meter were found to be good, the level of precipitation allowed the electrical current to pass through the sandy soil with relative ease. Good quality raw survey data was therefore collected requiring minimal data processing. Datasets were composited and processed using DW Consulting's Terrasurveyor v.3.0.32.4; raw grid files, composites and raster graphic plots will be stored and archived in this format. Minimal processing algorithms were undertaken on the raw (Fig. 8) and processed datasets (Figs. 9 - 10); schedules are presented in Appendix 1.

Data composites were exported as raster images into AutoCAD. An interpretation plan based on the combined results of the raw, processed and xy trace plots (Figs. 8 – 10) has been produced (Fig. 11).

UTSI TriVue multi-frequency ground penetrating radar

The ground penetrating radar (GPR) survey was undertaken along survey traverses that were 0.50m apart, readings were taken at 0.05m intervals along the traverse. Ground water issues were a concern on site with downpours occurring before and during the survey, however the free draining nature of the sandy geology helped to disperse the rainwater, allowing the conditions overall to be suitable for GPR survey.

Instrument calibration and settings

The TriVue contains three antennas of 250MHz, 500MHz and 1GHz central frequency within the casing, which allows the operator optimum flexibility when surveying. This antenna casing is strapped to a four-wheeled cart, allowing traverses to be recorded with relative ease, all three antennas were operated in unison, each of their recording lengths were independently adjusted giving the operator optimum control over antenna depths whilst allowing quality control measures to be implemented in the field.

Data capture

Ground penetrating radar survey points were recorded on a tablet linked to an odometer trigger, data were recorded and checked for quality during the survey, and further composited in the evenings, which allowed traverses to be re-surveyed if required. The data recorded by all three antennas was recorded and processed, the 500MHz antenna was found to be most suitable over this geology. A proforma survey sheet was created to allow the traverse composite to be constructed. Data were filed in unique project folders and backed up onto an external storage device and then a remote server in the evening.

Data software, processing and presentation

The ground conditions for the GPR were found to be suitable, allowing good quality data to be recorded. Individual traverses were processed using ReflexW 2D, a 3D cube was then created utilising ReflexW 3D, which enabled the production of timeslice data. The geometry file, raw files, processed files, cube files, timeslices and .mpg files will be stored and archived in this format. Processing algorithm schedules are presented in Appendix 1.

Timeslice data was exported out of ReflexW, into Terrasurveyor as raster images, these images were then imported into AutoCAD. An interpretation plan based on the combined timeslice results (Fig. 12) has been produced (Fig. 13).

5. Results

The three geophysical survey instruments will be discussed within their separate headings below, further comparisons will be discussed where anomalies strongly correlate between instruments (Fig. 14).

Fluxgate gradiometer survey (Fig's 4 - 7)

The site conditions for the fluxgate gradiometer survey were the most challenging of the three techniques employed, predominantly due to the increased magnetic background encountered within the bailey. A zero point was located in meadowland away from the site that allowed the sensors to be successfully calibrated. Despite the 'noisy' magnetic signature of the survey area a range of anomalies were recorded that have a high degree of archaeological potential.

A corner of two adjoining linear anomalies of magnetic disturbance (red hatching), orientated north-northwest to south-southeast and perpendicular were recorded in the dataset running along the southern boundary of the survey area and to the west of the

Tarmacadam drive (dark blue hatching). These anomalies are similar to those caused by services, however both appear to terminate within the survey area and are therefore more likely to be of a structural derivation. Low resistance and intermittent high resistance anomalies recorded by the earth resistance meter in the same location (Fig's 8 - 11) indicate that these structures may have been partially robbed-out to reclaim building materials for reuse sometime in the past.

One irregular area of magnetic disturbance (cyan hatching) located in the northeastern corner of the dataset is indicative of a dump of building material, or potentially a building platform. The ground penetrating radar survey recorded an area of high amplitude and the earth resistance meter prospected a high resistance linear anomaly in this same location, together this provides evidence for an anomaly of good archaeological potential.

An oval area of magnetic disturbance (magenta hatching) prospected in the southern half of the survey area is likely to record the location of a well-type structure, the readings are strongly magnetic and may indicate that it was built of brick. In this same location, the earth resistance meter records a blank area within structural remains and the GPR survey prospected an oval high amplitude response.

Areas of magnetic disturbance (green hatching) located on the periphery of the survey area record the presence of ferrous fences and benches positioned around the edge of the bailey.

Isolated dipolar anomalies (grey spots) were recorded within the dataset that are indicative of ferrous rubbish deposited within the bailey. It is possible that some of these responses are caused by ferrous archaeological finds or equally could derive from modern debris.

Earth resistance meter survey (Fig's 8 - 11)

The earth resistance meter survey was successful in recording a fairly narrow range of geophysical anomalies, some of which correlate well with anomalies prospected by both the magnetometer and GPR instruments.

High resistance linear anomalies (red hatching) were recorded in two orientations, the first being north-northeast to south-southwest and perpendicular and the second west-northwest to south-southeast and perpendicular. These responses are likely to be caused by building construction and may prove to be walls or foundations that belong to two separate phases of building activity. These results favourably correspond with linear anomalies recorded during both the magnetometer and GPR surveys and strongly suggest that the remains of buildings are still present below the ground surface of the castle's bailey.

Two areas of high resistance (magenta hatching) were recorded on the western and eastern periphery of the survey area, the deposits here are likely to be made up of moisture poor compacted materials. The larger high resistance anomaly located to the west is interpreted as an area of made ground used to level the surface of the bailey. It is possible that this material could derive from the demolition rubble of the structures recorded to the east. The smaller area of high resistance recorded in the southeastern corner of the dataset is of unknown origin.

Five linear areas of low resistance (dark blue hatching) record areas of moisture rich material within the dataset. The longest of which correlates well with the linear area of magnetic disturbance recorded by the fluxgate gradiometer (Fig. 7). The low resistance readings recorded indicate that no compacted materials are present here, therefore the anomaly is more likely to be a service trench or a robbed-out wall foundation trench.

Eleven discrete low resistance anomalies (cyan hatching) were prospected, many of which are located close to the anomalies indicative of structural remains. The character of this material indicates that it has a high moisture content and is therefore likely to be saturated material abutting the walls or naturally occurring geological variations.

Ground penetrating radar survey (Fig's 12 - 13)

The ground penetrating radar performed favourably over the survey area, recording anomalies of high archaeological potential. Its results correlate with those recorded by the other two techniques, confirming the presence of anomalies in some areas and increasing the detail of anomalies recorded (particularly those of a structural nature).

High amplitude linear anomalies (red hatching) were recorded on two different alignments, north-northeast to south-southwest and perpendicular and west-northwest to east-southeast, indicative of structural remains within the bailey. These strongly correlate with some of the linear responses recorded by the earth resistance meter and are recorded from an estimated depth of 0.14m below ground level (BGL) to a depth of 1.92m BGL. The narrow linear responses may indicate the presence of internal wall subdivisions with the broader linear anomalies more indicative of external walls.

High amplitude area responses (magenta hatching) were prospected that further indicate the presence of structures in the form of building rubble remains or floor surfaces, one of which correlates with an area of magnetic disturbance recorded by the fluxgate gradiometer. These high amplitude area responses are likely to be associated with their linear counterparts (red hatching) that are described above.

An oval increased magnitude response (orange hatching) that is recorded from just below the ground surface (0.22m BGL) to an estimated depth of *c*. 2.50m below ground level has been interpreted as a well. It was the deepest anomaly of archaeological derivation recorded by the 500MHz antenna. An oval high magnetic response was prospected in the same location during the magnetometer survey and an area of low resistance was recorded in the centre of a linear high resistance anomaly on the earth resistance meter dataset.

Increased discrete responses (orange hatching) are likely to be indicative of potential debris deposits, potentially rubbish pits containing compacted material, or alternatively could be of a structural or geological origin.

One curvilinear high amplitude response (grey hatching) records the location of the extant Tarmacadam driveway located on the eastern boundary of the survey area.

An area of increased amplitude (blue hatching) prospected on the western boundary where high resistance readings were also detected by the earth resistance meter is likely to record the presence of material deposited to level the ground, material that may derivate from the demolition rubble of the structures that once stood in the bailey.

6. Conclusion & archaeological potential

Figure 14 draws together the combined interpretations of all three instruments, highlighting those anomalies that have significant archaeological potential. The anomalies fall within five types: in-situ structural remains, robbed-out/service trench runs, rubbish pits, demolition/levelling deposits, and extant modern furniture anomalies.

In-situ building structure remains (red hatching) are recorded on two different orientations indicating that there could be at least two different building phases present below the surface of the bailey at a depth ranging from *c*. 0.14 to 1.92m BGL. Examples of both broad and narrow linear anomalies were recorded that are potentially indicative of internal wall subdivisions and external wall remains. Associated with the walls are remnant structural remains (magenta hatching) that are likely to consist of highly compacted deposits, potentially demolition rubble from the former standing structures and/or floor surfaces. An oval response (orange hatching) prospected by both the magnetometer and GPR instruments has been interpreted as a brick-lined well, recorded from *c.* 0.22m to approximately 2.50m below the ground surface.

Linear trench backfill anomalies (cyan hatching) may derive from robbed-out wall or foundation trenches, however they could be indicative of service trench runs.

Two discrete moisture rich anomalies (dark blue hatching) recorded just to the southeast of the well are potentially indicative of rubbish pits associated with the building structures, a geological origin also cannot be ruled out.

Demolition and/or levelling deposits (green hatching) recorded by the GPR and earth resistance meter surveys may derive from rubble associated with the demolished building structures, or made ground material used to level the surface of the bailey.

The extant Tarmacadam drive (black hatching) is further depicted in Figure 14.

This programme of geophysical survey has for the first time provided strong evidence that structural remains are present below the ground surface within the bailey at Bungay Castle. The three instruments have proven to favourably complement each other with each technique providing information that has helped to better identify the nature and type of anomalies that were recorded.

7. Archive deposition

The paper and digital archive will be kept at the SACIC office in Needham Market, before deposition in the Suffolk County Council Stores in Bury St Edmunds.

8. Acknowledgements

The fieldwork was carried out by Tim Schofield, Cameron Bate and Ed Palka and was directed by Tim Schofield. Project management was undertaken by Rhodri Gardner. The report illustrations were created by Tim Schofield and the report was edited by Stuart Boulter.

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Survey Station	Easting	Northing
STN 01	633465.394	289749.086
STN 02	633522.395	289767.815
STN 03	633528.639	289748.814

Figure 3. Survey grid (dark blue), GPR traverses (cyan) & georeferencing information (magenta)

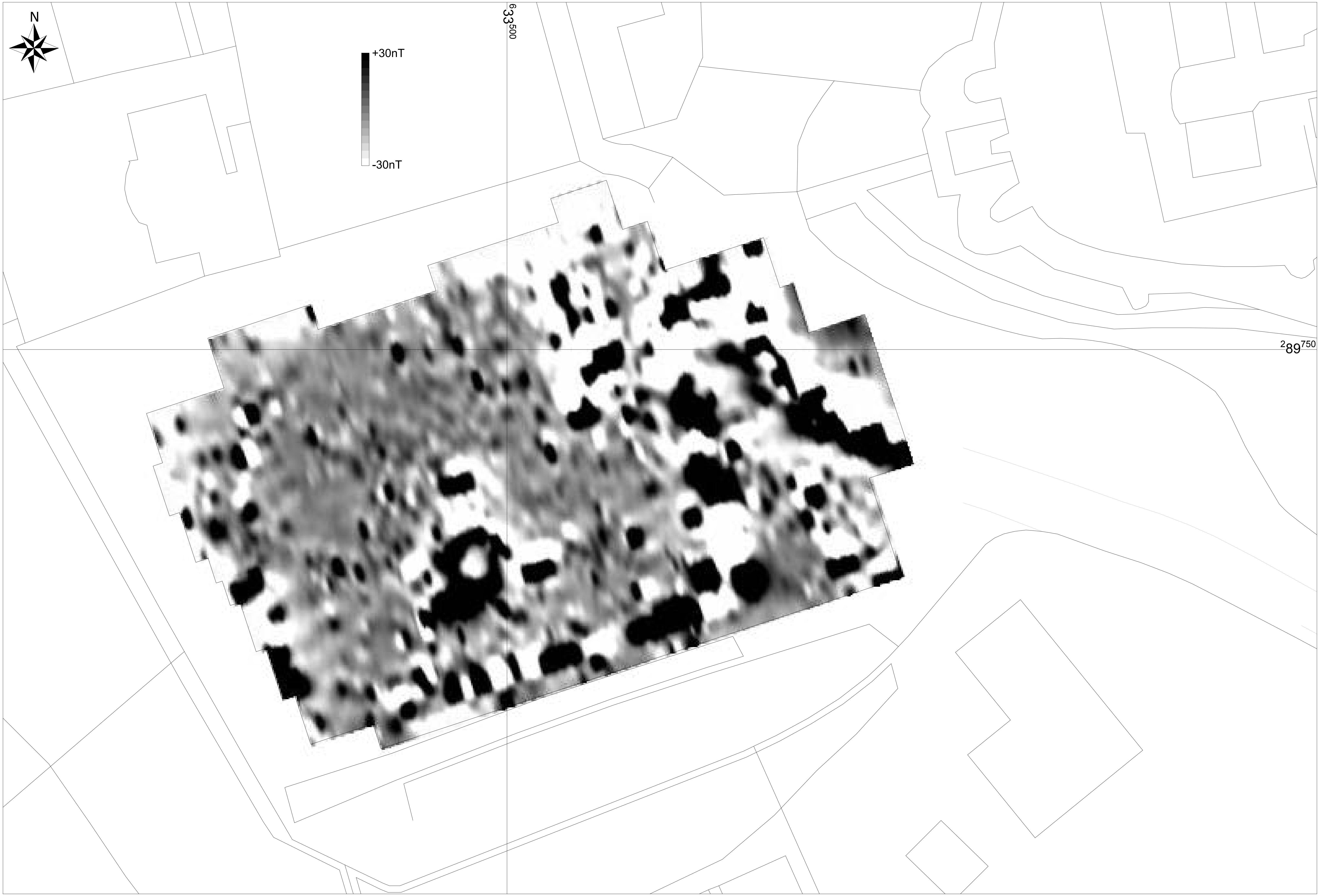

Figure 4. Raw magnetometer greyscale plot

Figure 5. Processed magnetometer greyscale plot

Figure 6. Processed magnetometer xy trace plot

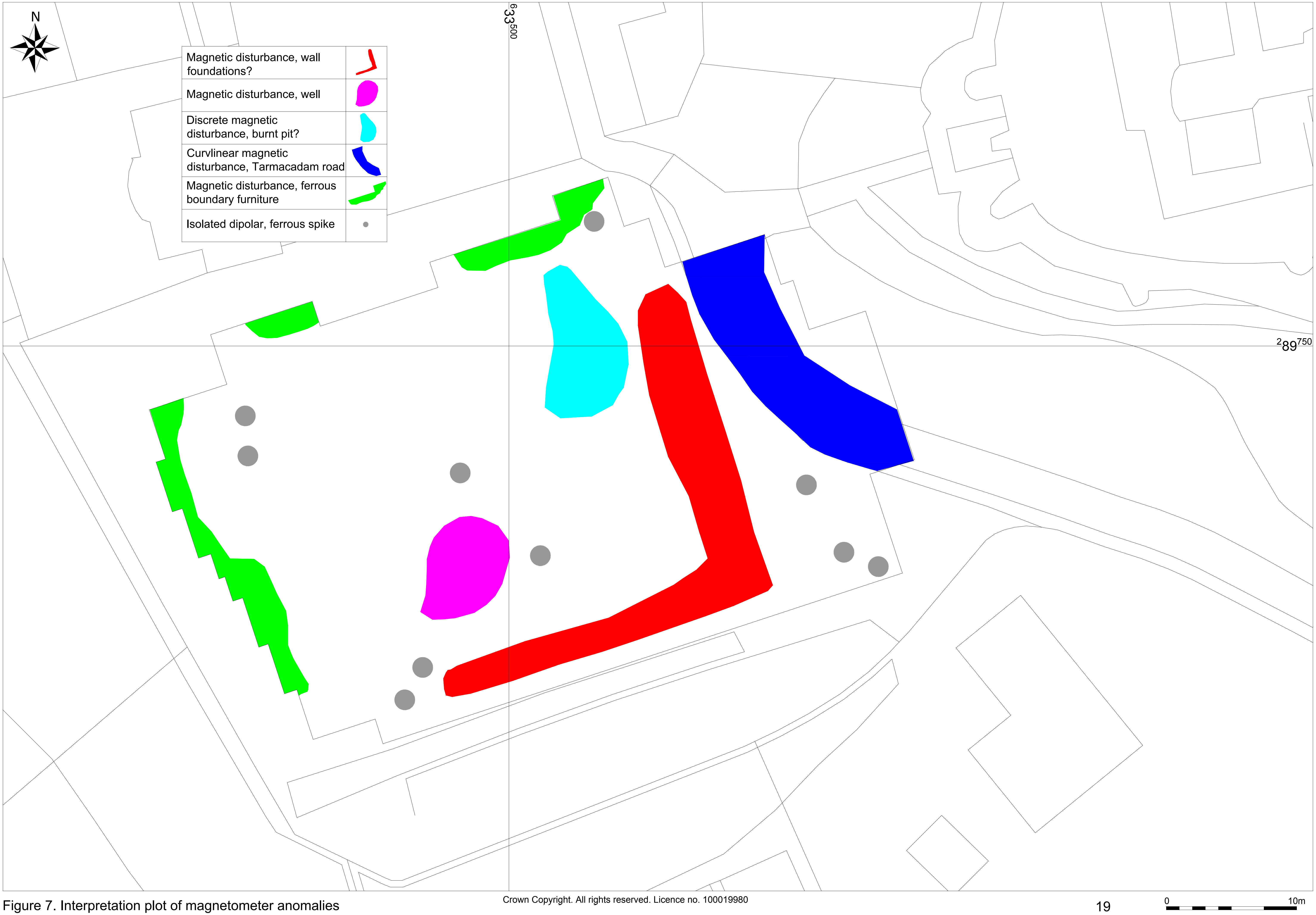

Figure 7. Interpretation plot of magnetometer anomalies

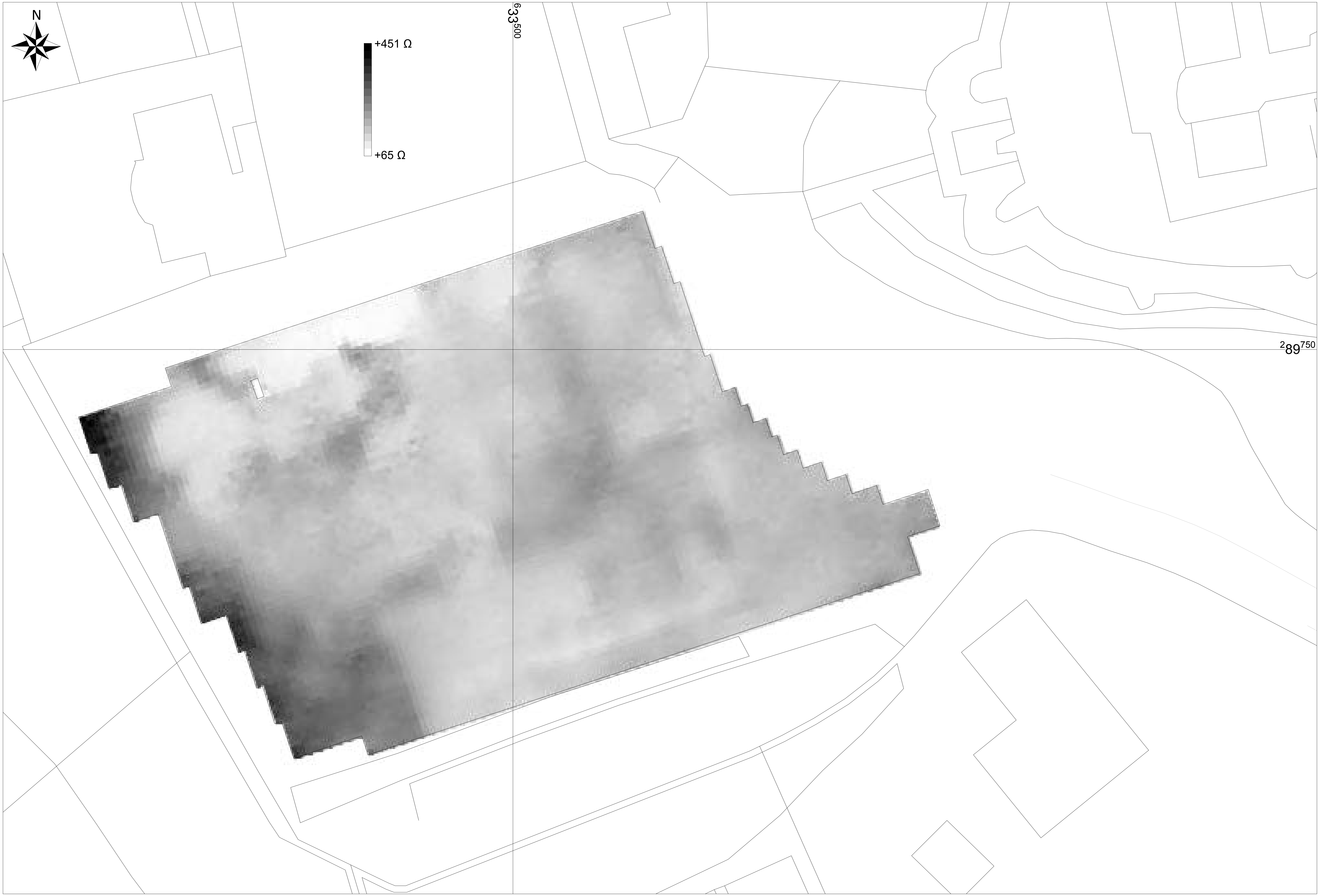

Figure 8. Raw earth resistance meter greyscale plot

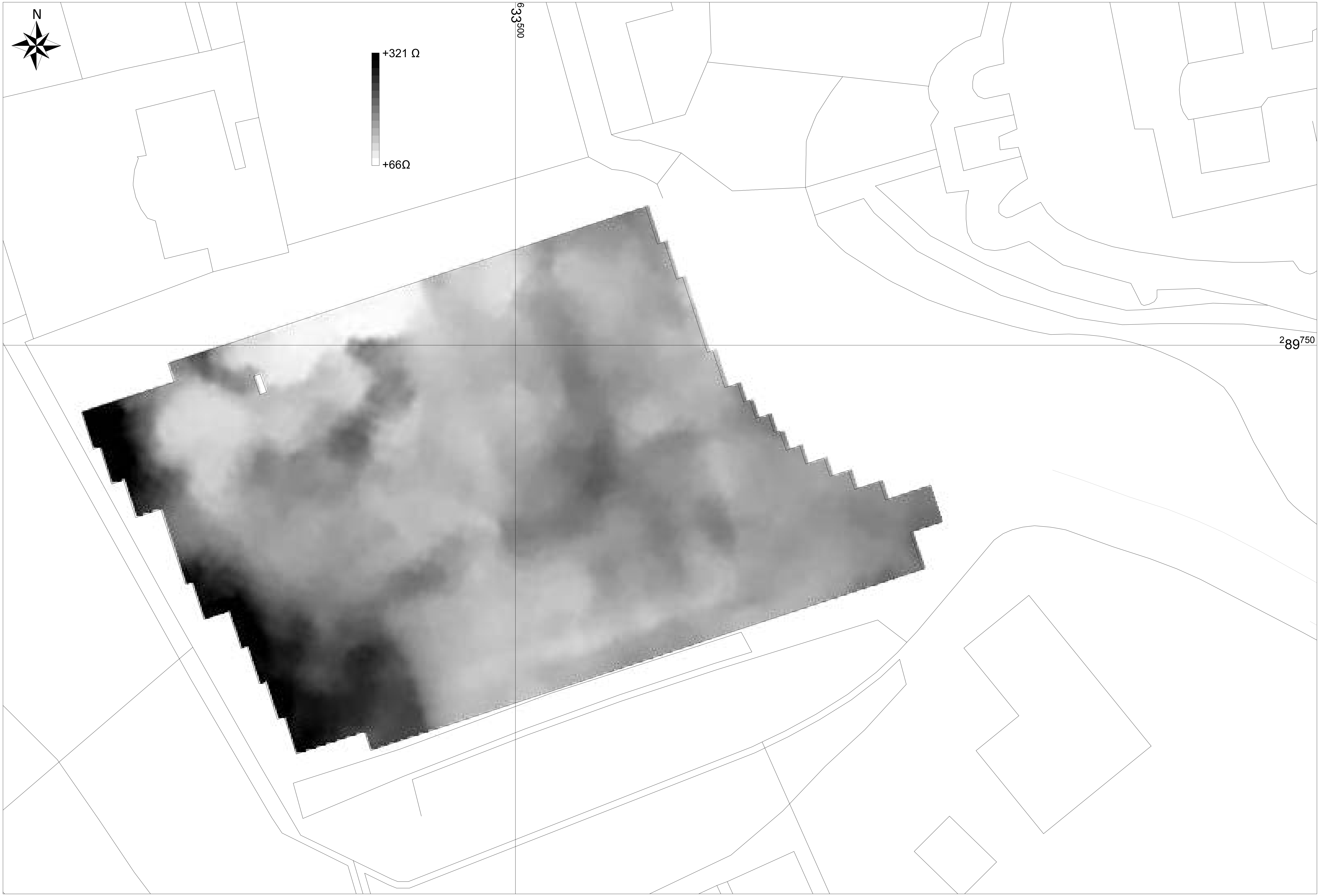

Figure 9. Processed earth resistance meter greyscale plot

Figure 10. Processed earth resistance meter xy trace plot

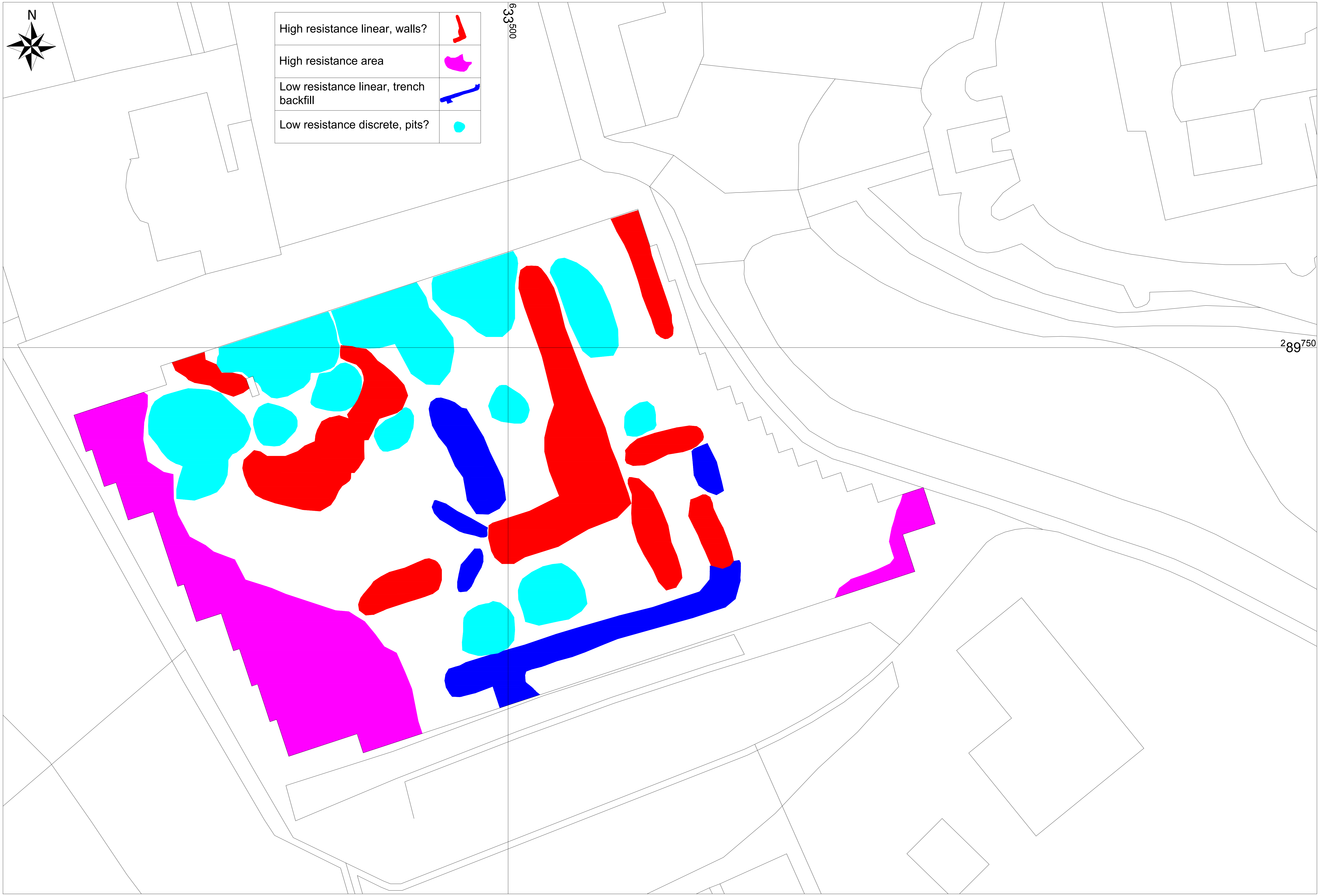

Figure 11. Interpretation plot of earth resistance meter anomalies

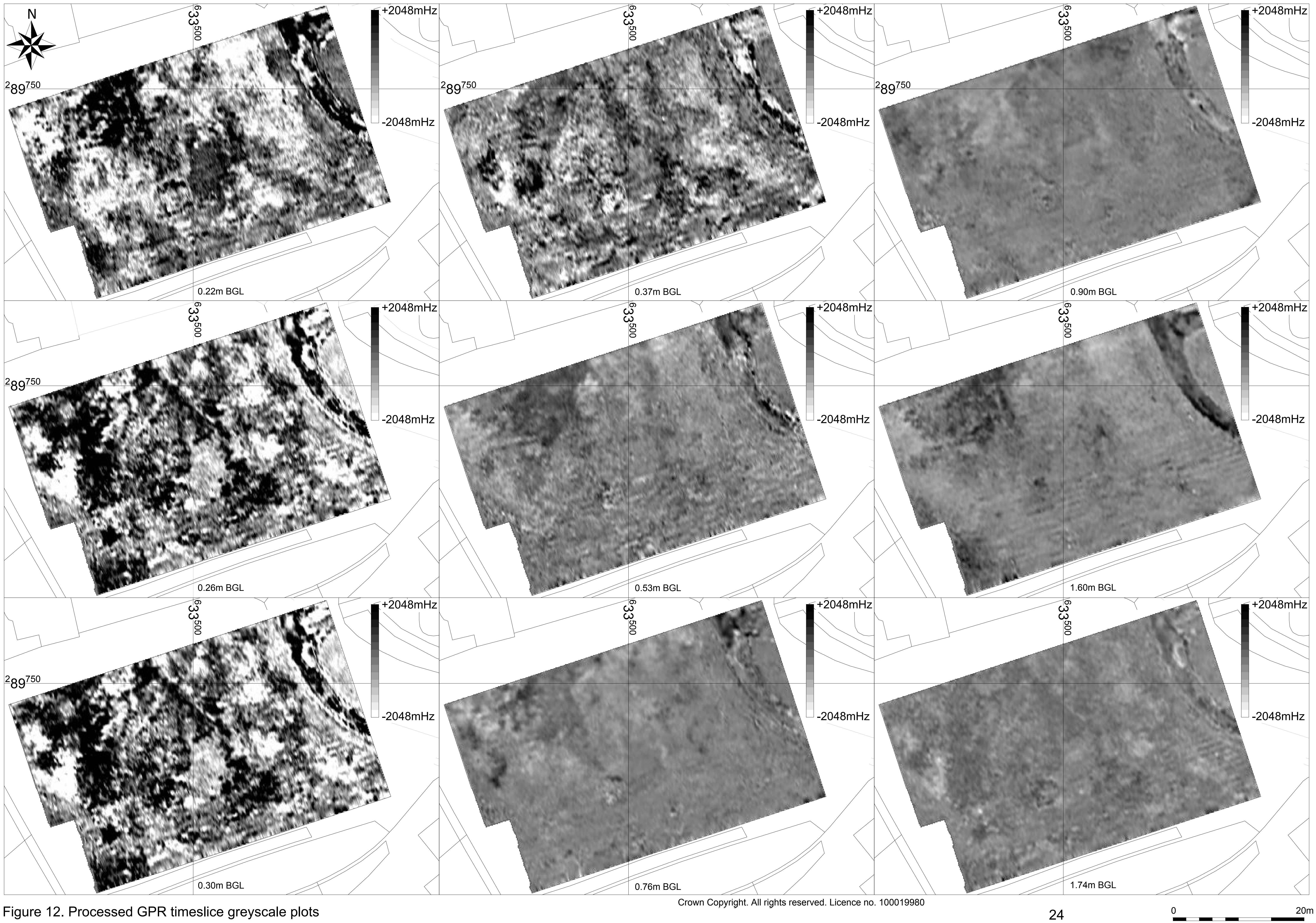

Figure 12. Processed GPR timeslice greyscale plots

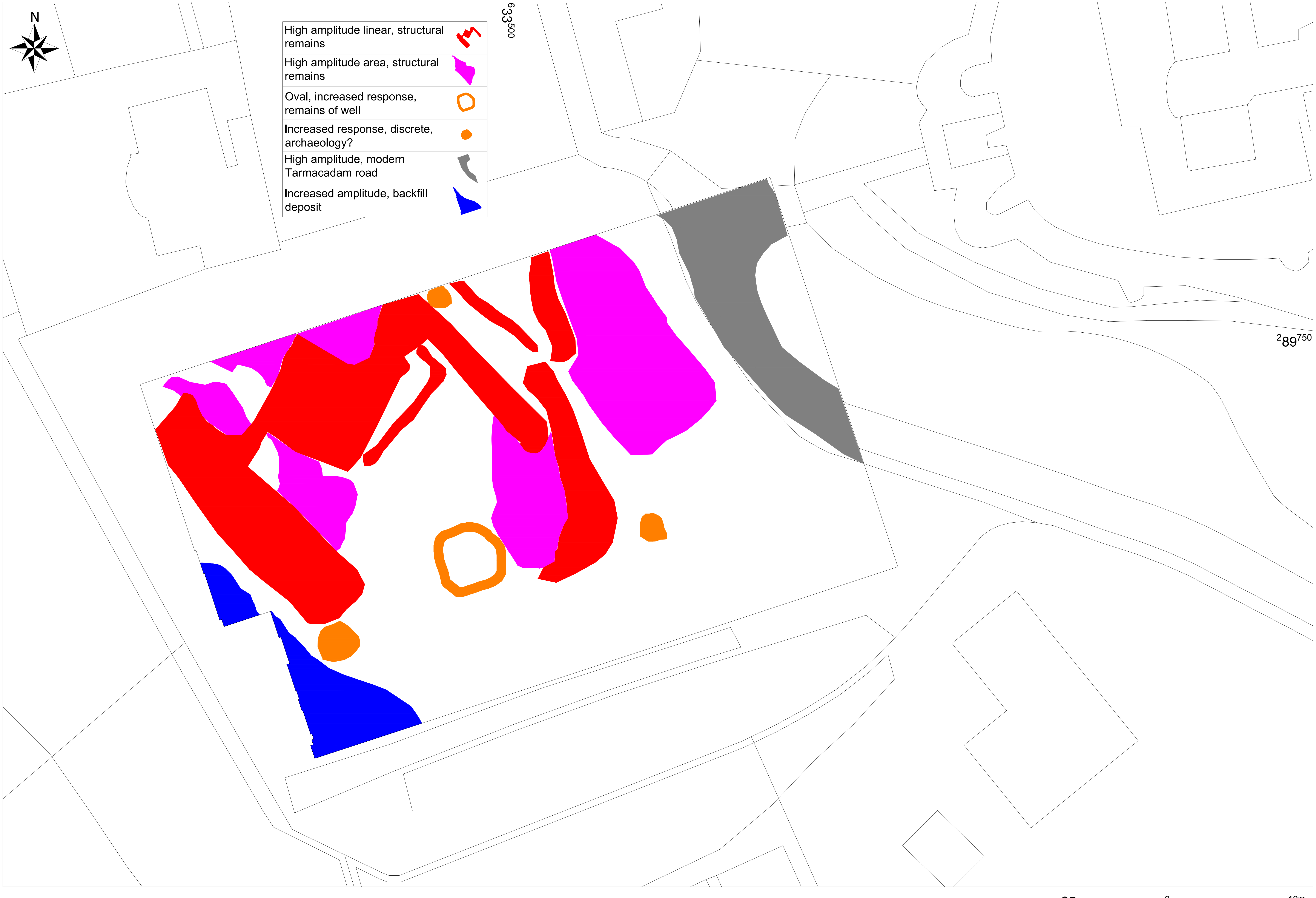

Figure 13. Interpretation plot of GPR anomalies

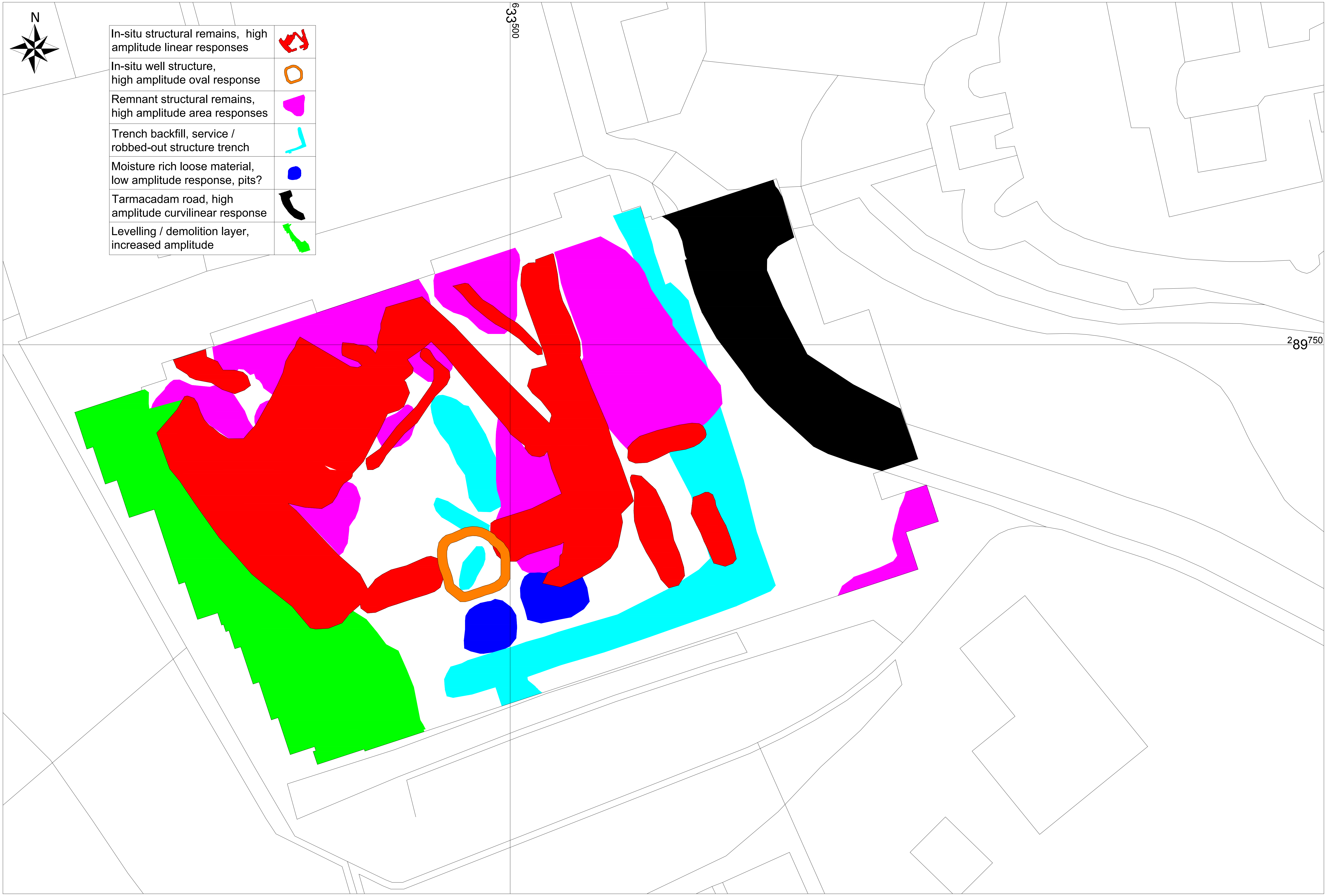

Figure 14. Combined interpretation plot of geophysical survey anomalies

Appendix 1. Metadata sheets

Fluxgate Gradiometer Survey

Grids

Source Grids: 6			
1	Col:0	Row:0	grids\01.xgd
2	Col:0	Row:1	grids\02.xgd
3	Col:1	Row:0	grids\03.xgd
4	Col:1	Row:1	grids\04.xgd
5	Col:2	Row:0	grids\05.xgd
6	Col:2	Row:1	grids\06.xgd

Raw Data

Filename	Bungay Mag Raw.xcp
Description	
Instrument Type	Grad 601 (Gradiometer)
Units	nT
Direction of 1st Traverse	90 deg
Collection Method	ZigZag
Sensors	2 @ 1.00 m spacing.
Dummy Value	2047.5
Dimensions	
Composite Size (readings)	240 x 40
Survey Size (meters)	60 m x 40 m
Grid Size	20 m x 20 m
X Interval	0.25 m
Y Interval	1 m
Stats	
Max	100.00
Min	-100.00
Std Dev	42.18
Mean	-7.50
Median	-6.70
Composite Area	0.24 ha
Surveyed Area	0.1608 ha
Program	
Name	TerraSurveyor
Version	3.0.32.4

Processes

Display Clip -30 +30

Graduated Shade

Processed Data

Filename	Bungay Mag Pro.xcp
Description	
Instrument Type	Grad 601 (Gradiometer)
Units	nT
Direction of 1st Traverse	90 deg
Collection Method	ZigZag
Sensors	2 @ 1.00 m spacing.
Dummy Value	2047.5
Dimensions	
Composite Size (readings)	240 x 40
Survey Size (meters)	60 m x 40 m
Grid Size	20 m x 20 m
X Interval	0.25 m
Y Interval	1 m
Stats	
Max	129.96
Min	-96.62
Std Dev	41.70
Mean	1.06
Median	0.00
Composite Area	0.24 ha
Surveyed Area	0.1608 ha
Program	
Name	TerraSurveyor
Version	3.0.32.4

Processes

Display Clip -30 +30

Graduated Shade

Destripe Median Sensors; All

Earth Resistance Meter Survey

Grids

Source Grids: 6
1 Col:0 Row:0 grids\01.xgd
2 Col:0 Row:1 grids\02.xgd
3 Col:1 Row:0 grids\03.xgd
4 Col:1 Row:1 grids\04.xgd
5 Col:2 Row:0 grids\05.xgd
6 Col:2 Row:1 grids\06.xgd

Raw Data

Filename	Bun Res Raw.xcp
Description	
Instrument Type	GeoScan (Resistance)
Units	Ohm
Direction of 1st Traverse	0 deg
Collection Method	ZigZag
Sensors	1
Dummy Value	2047.5
Dimensions	
Composite Size (readings)	120 x 120
Survey Size (meters)	60 m x 60 m
Grid Size	20 m x 30 m
X Interval	0.5 m
Y Interval	0.5 m
Stats	
Max	451.00
Min	65.00
Std Dev	51.88
Mean	167.25
Median	158.00
Composite Area	0.36 ha
Surveyed Area	0.15233 ha
Program	
Name	TerraSurveyor
Version	3.0.32.4

Processes

n/a

Processed Data

Filename	Bun Res Pro.xcp
Description	
Instrument Type	GeoScan (Resistance)
Units	Ohm
Direction of 1st Traverse	0 deg
Collection Method	ZigZag
Sensors	1
Dummy Value	2047.5
Dimensions	
Composite Size (readings)	120 x 120
Survey Size (meters)	60 m x 60 m
Grid Size	20 m x 30 m
X Interval	0.5 m
Y Interval	0.5 m
Stats	
Max	451.00
Min	66.00
Std Dev	51.24
Mean	166.98
Median	158.00
Composite Area	0.36 ha
Surveyed Area	0.15233 ha
Program	
Name	TerraSurveyor
Version	3.0.32.4

Processes

Despike, threshold 0.5m, window size 3 x 3, centre value median, replace with median

Display Clip +/-3SD (+66 / +321)

Graduated Shade

Ground Penetrating Radar Survey

Traverses: 64
20170808_100_ch2
20170808_101_ch2
20170808_103_ch2
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20170808_162_ch2
20170808_163_ch2

Processed Data

Description	
Instrument Type	Surfer ASCII
Units	MHz
Direction of 1st Traverse	0 deg
Collection Method	ZigZag
Sensors	1 x 500MHz
Dummy Value	2047.5
Dimensions	
Composite Size (readings)	1276 x 63
Survey Size (meters)	51 m x 31.5 m
Grid Size	51 m x 31.5 m
X Interval	0.04 m
Y Interval	0.5 m
Stats	
Max	5624.00
Min	-3178.00
Std Dev	473.26
Mean	0.29

Median	0.00
Composite Area	0.16078 ha
Surveyed Area	0.16078 ha
Program	
Name	ReflexW/TerraSurveyor

Processes

1. Starttime, move to -0.93
2. Dewow, 60ns
3. Subtract DC Shift
4. Band Pass, Frequencies, 62.5, 250, 1000, 1250
5. Band Pass, Butterworth, 250, 3000
6. Background removal, 58.94531
7. Gain, Manual Y, C curve
8. Kirchoff Migration, 30, 0.096

Appendix 2. Technical data

Detailed magnetometer survey

Detailed magnetometer survey is the most commonly employed archaeological geophysical prospection method in Britain; sensitive sensors can cost-effectively cover large areas of ground, rapidly recording anomalies that are indicative of cultural settlement activity. These anomalies can then be further investigated by field archaeologists to quantify a form and function. The magnetometer is a passive instrument that detects both permanent thermoremanent and temporary magnetic responses.

Thermoremanent magnetism

When a material containing iron oxides, for example clay, is heated above the Curie point, weakly magnetic compounds transform in to highly magnetic oxides that can be detected by the sensors of a magnetometer (Clark, 1996). For instance, the iron oxide haematite has a Curie temperature of 675 Celsius and magnetite 565 Celsius. Once these temperatures are reached, the oxides become demagnetised, on cooling their magnetic properties become permanently re-magnetised and align in the direction of the Earth's magnetic field (Gaffney and Gater, 2003). Over time the direction of the Earth's magnetic field changes allowing these directional differences to be detected by the magnetometer.

Strongly heated features such as hearths, kilns or furnaces frequently reach the Curie temperature and become permanently magnetised. These permanent magnetic responses are some of the strongest cultural features that can be recorded.

Temporary magnetism

Magnetic susceptibility is the ease with which a magnetic field can pass through a material, therefore the higher the material's magnetic susceptibility, the stronger the induced magnetic field will be. Temporary magnetisation occurs within material that is magnetically susceptible, this material acquires its own local magnetic field that combines with the Earth's magnetic field causing an anomaly to stand out from the background noise (Clark, 1996). These anomalies are subtler in nature, being derived from material that has been magnetically enhanced by cultural activity which has become concentrated into features over time. Anomalies that have temporary magnetisation include backfilled pits, ditches, field systems, occupation areas, land drains, remnant and existing field boundaries (David *et al*, 2014).

The key to a successful survey is having good contrast between the magnetic susceptibility of an archaeological feature with the surrounding superficial deposits. If there is no discernible difference between the two mediums it may be unlikely that the magnetometer will successfully prospect the feature. Archaeological features can also be masked by high magnetically susceptible topsoil, or deep overlying subsoil and colluvial deposits.

Ferrous anomalies

Ferrous objects are a common source of permanent magnetism, usually isolated with a strong dipolar signature. Some of these responses may have an archaeological derivation, however they are probably more indicative of modern iron objects introduced through manuring or lost within the topsoil.

Bartington DualGRAD 601-2 fluxgate gradiometers

Fluxgate gradiometers are the most commonly employed class of instrument in the UK. Two 1m sensitive sensors are affixed to a frame mounted 1m apart in a vertical plane and harnessed to the trunk of a geophysical surveyor or attached to a cart. Each sensor contains two fluxgate magnetometers with a 1m vertical separation. The sensor above records the Earth's magnetic field (magnetic background) while the sensor below records the local magnetic field. The two sensors need aligning before recording can begin and a zero station is located in an area with low magnetic variation for this purpose. After the sensors have been aligned, the survey can begin. When differences in the magnetic field strength occur between the two vertical magnetometers within each sensor, a positive or negative reading is recorded that is relative to the magnetic background of the zero station. Positive anomalies include pits, ditches and agricultural furrows. Negative anomalies commonly prospected include earthwork embankments, land drains and geological features.

Sensors are normally mounted to a height of 0.30m above the surface, and can detect to a depth of between one and two metres below the ground. The first survey traverse is commonly undertaken in an east to west direction.

Magnetic anomalies

Isolated dipolar responses

Isolated dipolar responses are commonly recorded throughout a dataset and are usually indicative of modern ferrous material deposited within the topsoil horizon. In some instances, the anomalies may be of an archaeological derivation. They are isolated, strong and dipolar in character.

Areas of magnetic disturbance

These anomalies are usually caused by building demolition rubble, ferrous boundaries, slag waste dumps, modern buried rubbish, pylons and services. Strong and dipolar in character, they are commonly recorded over a wide area.

Linear trends

Linear trends can be either positive or negative magnetic responses depending on the nature of the material present within the feature. If the anomaly is broad and weak, it is more likely to be of geological origin. Stronger positive linear trends are more likely to be of archaeological derivation, caused by settlement activity washing rich humic, charcoal and fired deposits into a feature. Negative linear trends are more commonly associated with bank deposits or land drains, with the less magnetically susceptible superficial deposits deposited at the top of the feature. Curvilinear trends are usually of archaeological origin, commonly interpreted as ring ditches or drip-gullies.

Discrete anomalies

Discrete anomalies can either be positive or negative in nature recorded within a localised area. Those that are positive are more likely to be of an archaeological origin, with negative discrete anomalies more commonly interpreted as natural geological variations.

Thermoremanent responses

These responses are caused by the heating of material containing iron to above the Curie temperature, they are strong and discrete in nature. In Britain high positive readings are recorded to the south of the anomaly with high negative readings recorded to the north.

Earth Resistance Meter

Soil resistance

The earth's soil has an electrical property known as conductivity or low resistance, that can be exploited by geophysical surveyors when prospecting for archaeological features. Naturally occurring minerals within the soil can be broken down by rainwater forming electrolytes, that further break down into positive and negative ions. When a current is inserted into the ground these ions will either attract or repel the current, driving it through the matrix along the path of least resistance.

Two sets of probes are employed to measure the relative resistance of the soil matrix; the first are the current probes which inject an electrical signal into the soil that is measured by a second set of potential probes recording the current's density. Archaeological features contain varying amounts of soil moisture, for example a loose moisture-rich pit or ditch will allow an injected electrical current to pass through it with relative ease, increasing the current density whilst decreasing the potential gradient and recording a low resistance anomaly within the dataset. Conversely a wall or road that is structurally dense, will repel the current, driving it above and below the feature on its journey through the matrix, decreasing the current density and increasing the potential gradient recording a high resistance anomaly.

Earth Resistance Meters

A single twin (pole-pole) probe array was employed to undertake this survey, using one set of mobile probes that along with the instrument box are mounted to the frame, recording individual data points within the survey grid, and remote probes that are located at least 15m beyond the edge of the grid to avoid feedback. The remote probes act as a static control station that the mobile probe readings are measured against. A 50m cable connects the remote probes to the instrument box; to progress the survey the static station will need to be moved. A control reading is taken before and after the remote probes are moved, to enable grid matching from one section to another. The mobile probes are mounted 0.5m apart on the frame, with the remote probes pushed into the ground approximately 3 – 4m apart. Once the mobile probes are placed onto the ground surface an electrical circuit is formed between the current electrodes of the remote and mobile probes; the potential gradient between the remote and mobile probes is then automatically recorded by the instrument. Removing the mobile probes from contact with the ground resets the instrument ready for the next point, as soon as the probes touch the ground a circuit is once again formed; this point is then auto-logged by the instrument.

Resistance anomalies

Discrete anomalies

Discrete anomalies can be recorded with both high and low resistance, those with low resistance are likely to be moisture-rich and those with high resistance are likely to have low moisture content compared with the surrounding matrix. Examples of low resistance anomalies include naturally occurring pockets of differing material within the geology, tree hollows or throws, glacial infilling of natural hollows, ponds, culturally excavated and backfilled storage or rubbish waste pits. High resistance anomalies are recorded where naturally occurring stone deposits, structural post pads, kilns, oven and hearth, furnace linings, rubble dumps and dried out hard or compacted fills are encountered.

Linear trends

Linear anomalies can also be either high or low resistance. Once again those with low resistance are likely to be moisture rich and conversely those with high resistance are likely have a low moisture content. Examples of low resistance linear trends include periglacial troughs, agricultural or settlement ditches, service run trenches. Examples of high resistance linear anomalies include geological rock formations, buried foundations, walls, metalled tracks or road surfaces, ditch banks.

Ground penetrating radar

Electro-magnetic radiation

Ground penetrating radar (GPR) uses radar pulses to image the subsurface with electromagnetic radiation in the very high frequency (VHF) microwave band of the radio spectrum, between 10 and 1000mhz. A transmitter is employed to emit an electromagnetic pulse into the ground, when a change in the boundary between materials or a buried object is encountered, the energy from the pulse is either reflected, refracted or scattered back to the receiving antenna that records these variations.

The best results from a ground penetrating radar survey are achieved where well defined changes in the electromagnetic properties of deposits are encountered, gradual change is more complicated to detect. Ground penetrating radar is therefore good at prospecting for service pipes, buried buildings and changes in stratigraphic soil horizons, it can also record voids within structures.

Depth measurement can also be estimated depending on the soil types encountered. Dry sandy soils or objects that contain low moisture content, for example building materials or stone bedrock, tend to be resistive rather than conductive and therefore a few meters of depth penetration can be gained. Conversely in moist and/or clayey soils and in materials that have high electrical conductivity, penetration can be as little as a few centimetres. The centre frequency transmitted by the antenna, and the radiated power may also limit the effective depth range of the GPR survey.

Higher frequencies do not penetrate the ground as deep as lower frequency antennas, however higher frequency antennas do provide better resolution compared with those of a lower frequency. Therefore, the operating frequency will always be a compromise between acquiring high enough resolution with the need for gaining sufficient depth penetration.

Utsi TriVue ground penetrating radar

An UTSI TriVue multi-frequency Ground Penetrating Radar (GPR) system will be used employing three antennas of 250MHz, 500MHz and 1GHz central frequency, which will allow optimum operator flexibility throughout the survey. The antennas are strapped to a four-wheeled cart allowing traverses to be recorded with relative ease, all three antennas are operated in unison, each of their recording lengths can be independently controlled giving the operator greater control over data acquisition allowing quality control measures to be implemented in the field.

Ground penetrating radar anomalies

High amplitude anomalies are strong and well defined, they can be caused by walls, foundations, culverts, vaults and service pipes, these anomalies can be discrete or linear trends.

Increased amplitude anomalies are usually weaker and less well defined but could be of potential archaeological derivation, for example rubble spreads, or anomalies that form good contrast patterns of potential archaeological derivation.

Low amplitude anomalies, offer little contrast and form incomplete patterns, they are of potential archaeological origin however a modern or natural derivation cannot be ruled out.

Appendix 3. OASIS form

OASIS DATA COLLECTION FORM: England

Printable version

OASIS ID: suffolka1-290477

Project details

Project name	Bungay Castle, Bungay, Suffolk, Geophysical Survey
Short description of the project	In July and August 2017 Suffolk Archaeology Community Interest Company (SACIC) undertook detailed geophysical surveys within the bailey of Bungay Castle, Bungay, Suffolk. Three techniques were requested by Historic England to be deployed over the 0.24 hectare grass covered bailey, comprising fluxgate gradiometer, earth resistance meter and ground penetrating radar surveys. The three instruments highlighted a narrow range of geophysical anomalies that have significant archaeological potential, including in-situ structural remains that may include walls, floors and a potential well. Anomalies indicative of robbed-out or service trench runs, rubbish pits or geological deposits, demolition or levelling deposits and an extant Tarmacadam drive were further prospected.
Project dates	Start: 13-07-2017 End: 16-08-2017
Previous/future work	Yes / Not known
Any associated project reference codes	BUN 004 - Sitecode
Any associated project reference codes	ESF 25629 - HER event no.
Type of project	Field evaluation
Site status	Scheduled Monument (SM)
Current Land use	Other 8 - Land dedicated to the display of a monument
Monument type	ANOMALIES INDICATIVE OF A WATER WELL Uncertain
Monument type	ANOMALIES INDICATIVE OF BUILDING STRUCTURES Uncertain
Monument type	ANOMALIES INDICATIVE OF ROBBED-OUT WALLS Uncertain
Monument type	ANOMALIES INDICATIVE OF DEMOLITION RUBBLE Uncertain
Monument type	ANOMALIES INDICATIVE OF MADE GROUND LAYERS Uncertain
Significant Finds	NONE None
Methods & techniques	"Geophysical Survey"
Development type	Not recorded
Prompt	Scheduled Monument Consent
Position in the planning process	Not known / Not recorded
Solid geology (other)	Crag Group Sands
Drift geology	RIVER TERRACE DEPOSITS
Techniques	Magnetometry

Techniques	Resistivity - area
Techniques	Ground penetrating radar

Project location

Country	England
Site location	SUFFOLK WAVENEY BUNGAY Bungay Castle
Study area	0.16 Hectares
Site coordinates	TL 3350 8973 52.488741380202 -0.033595134403 52 29 19 N 000 02 00 W Point
Height OD / Depth	Min: 10m Max: 10m

Project creators

Name of Organisation	Suffolk Archaeology CIC
Project brief originator	English Heritage/Department of Environment
Project design originator	Nick Carter
Project director/manager	Rhodri Gardner
Project supervisor	Tim Schofield
Type of sponsor/funding body	Other Charitable Trust
Type of sponsor/funding body	English Heritage
Name of sponsor/funding body	Bungay Castle Trust and Historic England

Project archives

Physical Archive Exists?	No
Digital Archive recipient	Suffolk HER
Digital Contents	"Survey"
Digital Media available	"Database","Geophysics","Images raster / digital photography","Images vector","Moving image","Survey","Text"
Paper Archive recipient	Suffolk HER
Paper Contents	"Survey"
Paper Media available	"Map","Plan","Report","Survey ","Unpublished Text"

Project bibliography 1

Publication type	Grey literature (unpublished document/manuscript)
Title	Bungay Castle, Bungay, Suffolk; Geophysical Survey
Author(s)/Editor(s)	Schofield, T. P.
Other	Report No. 2017/078

bibliographic details	
Date	2017
Issuer or publisher	Suffolk Archaeology CIC
Place of issue or publication	Needham Market
Description	Bound A4 Report with A3 fold-out figures
URL	www.suffolkarchaeology.co.uk
Entered by	Tim Schofield (tim.schofield@suffolkarchaeology.co.uk)
Entered on	26 September 2017

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