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Blood Hill, Lynford and Thetford, Norfolk

Report on Geophysical Surveys, May 2024

Megan Clements, Neil Linford, Paul Linford, Andrew Payne and Nathalie Barrett

Geophysics

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Summary

Ground Penetrating Radar (GPR) (0.21ha) and earth resistance (0.19ha) surveys together with an Electrical Resistance Tomography (ERT) profile (87m) were conducted over the mound known as Blood Hill, Thetford Forest, Thetford, following a request by the Historic England East of England Regional Team to identify and locate the full extent of the barrow and any evidence for a buried ditch. The geophysical surveys suggest the current monument covers an original, circular barrow mound and some anomalies suggest the encircling barrow ditch has been infilled. The earth resistance and ERT results also support a tentative interpretation that the barrow was originally higher and has been flattened either through deliberate landscape re-shaping, erosion associated with the ride and movement across the mound, or through excavation into the monument.

Contributors

The geophysical fieldwork was conducted by Megan Clements, Neil Linford, Paul Linford, Andrew Payne and Nathalie Barrett.

Acknowledgements

The authors are grateful for the help of the Forestry Commission for their permission and assistance to gain access to Blood Hill to allow the survey to take place. The cover image shows the earth resistance survey in progress over the northern extent of the barrow mound (photograph taken by Neil Linford).

Archive location

Historic England, Fort Cumberland, Fort Cumberland Road, Portsmouth, PO4 9LD.

Date of survey/research/investigation

The surveys were conducted on the 14th May 2024 with a second site visit on the 26th July 2024. The report was completed on the 14th of August 2024.

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Introduction

Ground Penetrating Radar (GPR) and earth resistance surveys together with an Electrical Resistance Tomography (ERT) transect were conducted at Blood Hill, Thetford Forest, Thetford, Norfolk (Figures 1 and 2). The aim of the survey was to identify and locate the full extent of the barrow and any evidence for a buried ditch following a request from the Historic England East of England Regional Team. A Forestry Commission ride passes alongside the barrow and it is unclear whether the currently scheduled area adequately protects buried archaeology associated with the monument. If a wider curtilage is required, it will necessitate tree felling to reroute the forest ride and provide the appropriate protection. Hence a clear appreciation of the full extent of archaeological remains was required to justify this action.

The monument (NHLE: 1015255 and depicted on the OS base mapping data Figures 1 and 2) is situated on a part of a track following the parish boundary between Thetford to the east and Lynford to the west, and it includes a bowl barrow incorporated in the remains of a boundary bank. The barrow is visible as an oval earthen mound measuring ~29m by ~40m and standing to a height of ~0.5m. This mound forms the central part of a more elongated earthwork which extends at a slightly lower height, tapering gradually for a distance of ~12.5m at either end of the mound along the same axis, and which is considered to be the remains of a boundary bank. The barrow mound has a truncated appearance on the eastern side and is thought originally to have covered an approximately circular area with an estimated diameter of ~34m. It has also been reduced in height as a result of forestry cultivation, and when first recorded, was ~2.6m in height (Historic England 1997). The full extent of the scheduled area containing barrow could not be surveyed due to the presence of dense vegetation.

The bedrock geology consists of Lewes Nodular Chalk with no superficial deposits recorded (Geological Survey of Great Britain 2010; British Geological Survey 2024). Freely draining, sandy, Breckland soils of the Worlington association (554b) have developed over the site (Soil Survey of England and Wales 1983; Soilscapes 2024). The area is also well known for periglacial and solution features including aeolian deposits of Coversand that blanket much of the topography within the district.

The barrow was covered in long grass with several deep depressions, mostly in the east of the barrow, and the remains of a former timber fence line could be observed at various points across the mound. The weather was mostly overcast with intermittent spells of light rain.

Method

Ground Penetrating Radar

A 3d-Radar (Kontur) MkIV GeoScope Continuous Wave Step Frequency (CWSF) Ground Penetrating Radar (GPR) system was used to conduct the survey collecting data with a multi-element DXG1820 vehicle towed, ground coupled antenna array (Linford *et al.* 2010; Eide *et al.* 2018). A roving Trimble R8s Global Navigation Satellite System (GNSS) receiver was mounted on the GPR antenna array, that together with a second R8s base station was used to provide continuous positional control for the survey collected along the instrument swaths shown on Figure 1. The GNSS base station receiver was adjusted to the National Grid Transformation OSTN15 using the Trimble VRS Now Network RTK delivery service. This uses the Ordnance Survey's GNSS correction network (OSNet) and gives a stated accuracy of 0.01-0.015m per point with vertical accuracy being half as precise. Ordnance Datum Newlyn (ODN) was used for elevation data.

Data were acquired at a 0.075m x 0.075m sample interval across a continuous wave step frequency range from 40MHz to 2.99GHz in 4MHz increments using a dwell time of 2ms. A single antenna element was monitored continuously to ensure data quality during acquisition together with automated processing software to produce real time amplitude time slice representations of the data as each successive instrument swath was recorded in the field (Linford 2013).

Post-acquisition processing involved conversion of the raw data to time-domain profiles (through a time window of 0 to 75ns), adjustment of time-zero to coincide with the true ground surface, background and noise removal, and the application of a suitable gain function to enhance late arrivals. Representative profiles from the full GPR survey data set are shown on Figure 6 together with volumetric models of data both draped over the site topography and as cut-away sections. To aid visualisation amplitude time slices were created from the entire data set by averaging data within successive 2.5ns (two-way travel time) windows (e.g. Linford 2004). An average sub-surface velocity of 0.0971m/ns was assumed following constant velocity tests on the data and was used as the velocity field for 2D Kirchoff migration and time to estimated depth conversion, including appropriate topographic and tilt angle corrections to account for topographic variation (Goodman *et al.* 2006).

Each of the resulting time slices therefore represents the variation of reflection strength through successive ~0.12m intervals from the ground surface, shown as individual greyscale images in Figures 3 and 7 to 9. Further details of both the frequency and time domain algorithms developed for processing this data can be found in Sala and Linford (2012).

Due to the size of the resultant data set a semi-automated algorithm has been employed to extract the vector outline of significant anomalies shown on Figure 11. The algorithm uses edge detection to identify bounded regions followed by a morphological classification based on the size and shape of the extracted anomalies. For example, the location of possible pits is made by selecting small, sub circular anomalies from the data set (Linford and Linford 2017).

Earth Resistance

Measurements were recorded over a series of 30m grids established with a Trimble R8s GNSS, Figure 2, using a Geoscan RM85 earth resistance meter, internal multiplexer, and a PA5 electrode frame in the Twin-Electrode configuration, to allow two separate surveys, with mobile electrode separations of 0.5m and 1.0m, to be collected simultaneously. The 0.5m mobile electrode separation coverage was designed to detect near-surface anomalies in the upper 0.5m of the subsurface whilst the 1.0m separation survey allowed anomalies to a depth of about 1-1.25m to be detected. For the 0.5m mobile electrode separation survey readings were taken at a density of 0.5m x 1.0m whilst for the 1.0m separation survey they were taken at a density of 1.0m x 1.0m.

Extreme values caused by high contact resistance were suppressed using an adaptive thresholding median filter with radius 1m (Scollar *et al.* 1990). The results for the near-surface 0.5m mobile electrode separation survey are depicted as a linear greyscale image in Figure 4 superimposed on the base OS mapping data. Figure 10 shows the minimally processed data from both the 0.5m and 1.0m mobile electrode separation data, presented as trace plots, linear and histogram equalised greyscale images of the processed datasets following the application of extreme value noise reduction. The application of a Wallis contrast-enhancing filter has also been applied to both the 0.5m and 1.0m data sets with a radius of 3m and edge to background ratio of 0.5.

Electrical Resistance Tomography

A single 87m long ERT profile was measured consisting of a line of 88 electrodes spaced 1m apart. The profile was located using a Trimble R8s Global Navigation Satellite System (GNSS) receiver adjusted to the National Grid Transformation OSTN15 using the Trimble VRS Now Network RTK delivery system. This uses the Ordnance Survey's GNSS correction network (OSNet) and gives a stated accuracy of 0.01-0.015m per point with vertical accuracy being half as precise. Ordnance Datum Newlyn (ODN) was used for elevation data. The profile was located based on ground observations and to take a cross-sectional profile of the Hill. Once the profile was established, the individual electrode positions (E1-88) and heights were recorded using the GNSS system. The location of the profile superimposed onto base Ordinance Survey (OS) mapping is depicted in Figure 2.

Earth resistance measurements were made with a Campus Tigre multiplexed earth resistance meter controlled by ImagerPro2006 software running on a field laptop computer. The expanding Wenner alpha electrode configuration was employed owing to its high signal to noise ratio. Despite best efforts to reseat and dampen the soil around electrodes it was not possible to reduce all electrode contact resistances below the recommended 1500 Ω threshold owing to the high sand content of the soil. This has limited the depth of current penetration and thus the maximum depth imaged by the electrical section. It has also affected data quality and, even at shallower depths where readings were generally possible, several stations had to be excluded from the inversion where it was not possible to measure a non-zero resistance.

Data from the profile was inverted to infer subsurface resistivity models using Geotomo Software's Res2dinv software (version 3.56.39), with the measurements of the electrode positions incorporated to allow topographic correction. Error estimation during the inversion used the robust inversion method (absolute errors or the L1 norm) which is more tolerant of discontinuities between adjacent cells and thus tends to resolve boundaries between layers more sharply than the standard least mean squares inversion. A colour image of the resistivity output model profile is shown in Figure 5.

Results

Ground Penetrating Radar

A graphical summary of the significant GPR anomalies, [**gpr1-13**] discussed in the following text, superimposed on the base OS mapping data, is provided in Figure 11.

Significant reflections have been recorded throughout the 75ns two-way travel time, although from a two-way travel time of ~60.0ns (2.93m) onwards there is only a diffuse dipping response ([**gpr1**] on Figure 6) which appears to be due to the underlying chalk geology. While there are few discernible anomalies within the near-surface data between 0.0 and 10.0ns (0.0 to 0.49m) some linear low [**gpr2**] and high-amplitude responses [**gpr3**] appear from 17.5ns (0.85m) onwards approximately parallel to the forestry ride and former boundary bank passing through the long axis of the barrow, and a visible ditch to the east of the mound.

A linear anomaly [**gpr4**] found between 12.5 and 20.0ns (0.61 to 0.97m) to the south of the barrow follows the line of the boundary bank shown on historic mapping and may continue as more subtle linear responses [**gpr5**] at approximately 32.5ns (1.58m) passing over the raised mound (OS Historic County Mapping Series: Norfolk 1843-1939 Epochs 1 to 3). Low-amplitude, pit-type anomalies [**gpr6**] are found between 12.5 and 32.5ns (0.61 to 1.38m) and may, possibly, be associated with former tree planting over the barrow.

A fragmented circular anomaly [**gpr7**] with a diameter of ~27m is found between 20.0 and 40.0ns (0.97 to 1.94m) appears to mark the outline of the barrow, perhaps as a circle of stones or compacted post pits. The response to [**gpr7**] appears closer to the current land surface on the eastern, more heavily eroded, flank of the barrow mound (Figure 6). Curvilinear anomalies of mixed response [**gpr8**] follow a visible depression to the east side of the mound but it is difficult to determine whether these are associated with erosion from the forest ride and recently removed fence line or, perhaps, an encircling barrow ditch. The original topographic expression of the barrow mound and ditch appears to have been obscured through a combination of erosion, forestry works and, perhaps, wind-blown sand deposits (Figure 6 (C), (D) and (E)).

Further fragmented anomalies [**gpr9**] are found within the circular barrow mound [**gpr7**] together with a gently dipping linear responses [**gpr10**] and [**gpr11**] between 20.0 and 27.5ns (0.97 to 1.34m). It is difficult to determine whether [**gpr9-11**] represent internal detail within the barrow mound, antiquarian intervention or more recent animal burrows.

A linear high amplitude anomaly [**gpr12**] is found immediately to the north-east of the barrow between 10.0 and 17.5ns (0.49 to 0.85m) and may be associated with a more diffuse, curvilinear response [**gpr13**] although it is difficult to suggest a more definitive interpretation.

Earth resistance

A graphical summary of significant earth resistance anomalies [**r1-6**] discussed in the following text superimposed on the base OS mapping data is provided in Figure 12.

The barrow is visible as a circular, high resistance anomaly [**r1**]. While to the north the elongated earthwork appears to gradually extend away from the centre of the barrow, the earthen mound to the south seems to join onto the barrow more abruptly. As the elongated topographic expression follows the line of the Forestry Commission ride and former boundary bank, it is possible the barrow itself was originally more rounded in shape, as opposed to its current, extended, lozenge shape. In the centre of the barrow is an elongated area of lower resistance [**r2**] which could indicate previous excavation but could also represent an original internal feature as no significant depression typical of antiquarian barrow digging is present on the surface in this area.

Another area of low resistance [**r3**] could possibly be due to moisture retention in the topographic dips observed during the survey on the east side of the mound, but may also relate to an internal pit feature of possible archaeological significance. Surrounding [**r2**] are a series of discrete low resistance anomalies to the east and high resistance responses to the west [**r4**] that can most clearly be seen in the 0.5m mobile electrode separation Wallis filtered data (Figure 10 (D)). While an archaeological origin cannot be discounted, these anomalies may be the result of localised geological and topographic change, especially the slightly larger low resistance anomalies to the east which are similar in response and location to [**r3**]. A second site visit was conducted on 24 July 2024 that confirmed the high resistance [**r4**] anomalies were not associated with the remains of former fence posts known to have once surrounded the Hill.

The central low resistance anomaly [**r2**] also appears to be bracketed by an area of higher resistance [**r5**]. The response at [**r5**] could represent either original mound construction material, or material later extracted from the central low resistance anomaly [**r2**]. The very high resistance anomaly [**r6**] at the southern end of the monument is also visible on the ERT results as [**ert3**]. It is difficult to determine if [**r6**] is associated with the barrow, however the ERT results support an interpretation that the anomaly results from later anthropogenic landscape changes. The surrounding diffuse spreads of high resistance material are most likely to be of geological origin, perhaps deposits of wind-blown sand.

Electrical Resistance Tomography

A graphical summary of significant ERT anomalies [**ert1**-**3**] discussed in the following text superimposed on the base OS mapping data is provided in Figure 5.

The ERT profile demonstrates that the high resistance material [**ert1**] that forms the barrow is ~0.5m – 1.0m thick. The centre of the mound [**ert2**] has only just been clipped by the profile and the high resistance material [**ert1**] seen on the slopes of the mound, is very thin over this location, possibly suggesting the original mound may have been higher and the high resistance material removed. The mound could have been reduced in height either by deliberate modification, erosion over time due to traffic on the forest ride that used to cross it, or possibly from a deliberately dug trench. It is also possible that wind-blown sand deposits have partially obscured the topography over the barrow and contributed to the near-surface high-resistance response.

An area of very high resistance has been detected along the southern topographic extent of the barrow, [**ert3**] (cf [**r6**]). While it is still difficult to determine an exact origin for [**ert3**], that such a high resistance anomaly is located at the foot of the barrow could suggest an original barrow ditch may have been in-filled by either natural processes such as wind-blown sand deposits, or by anthropogenic landscape shaping to make the area level for easier access for the ride across the top of the barrow.

Conclusions

Ground Penetrating Radar and earth resistance surveys suggest that, despite the lozenge-shaped topographic mound visible today, the current monument covers an original, circular barrow mound, which has been mapped by the two techniques. The encircling barrow ditch is less clear in the results, although some possible anomalies have been identified, supported by the ERT results, suggesting the ditch has been infilled, perhaps to reduce topographic variation for the ride over the mound. The ERT survey also possibly suggests the barrow may originally have been higher and has been flattened either through deliberate landscape re-shaping, erosion associated with the ride and movement across the mound, or through excavation into the mound.

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Figure 1: Location of GPR instrument survey swaths superimposed over the base OS mapping data (1:500).

Figure 2: Location of earth resistance survey grids and ERT profiles superimposed over the base OS mapping data (1:500).

Figure 3: GPR amplitude time slice between 22.5 and 25.0ns (1.09 to 1.21m) superimposed over the base OS mapping data (1:500).

Figure 4: Linear greyscale image of earth resistance 0.5m mobile electrode separation data superimposed over the base OS mapping data (1:500).

Figure 5: Colour-scale image of ERT resistivity output model profile with annotation of significant anomalies (1:250).

Figure 6: Representative topographically corrected profiles from the GPR survey shown as greyscale images (A) and (B) with annotations denoting significant anomalies. The location of the selected profiles can be found on Figures 1, 3 and 11. A GPR time slice between 22.5 and 25.0ns (1.09 to 1.21m) is shown in (C) draped over a Digital Terrain Model (DTM) of the site with a vertical (elevation) exaggeration of x 5. Two cut-away models of the GPR data volume are shown in (D) for the full topography of the site and (E) at an elevation of 24.7m revealing internal detail within the barrow (vertical (elevation) exaggeration of x 4).

Figure 7: GPR amplitude time slices between 0.0 and 25.0ns (0.0 to 1.21m) (1:750).

Figure 8: GPR amplitude time slices between 25.0 and 50.0ns (1.21 to 2.43m) (1:750).

Figure 9: GPR amplitude time slices between 50.0 and 75.0ns (2.43 to 3.64m) (1:750).

Figure 10: (A) Trace plot, (B) linear and (C) histogram equalised greyscale images of the 0.5m mobile electrode separation minimally processed data with (D) linear greyscale image of Wallis contrast-enhanced data. (E), (F), (G) and

(H) show the same representations for the 1.0m mobile electrode separation data (1:750).

Figure 11: Graphical summary of significant GPR anomalies superimposed over the base OS mapping data (1:500).

Figure 12: Graphical summary of significant earth resistance anomalies superimposed over the base OS mapping data (1:500).

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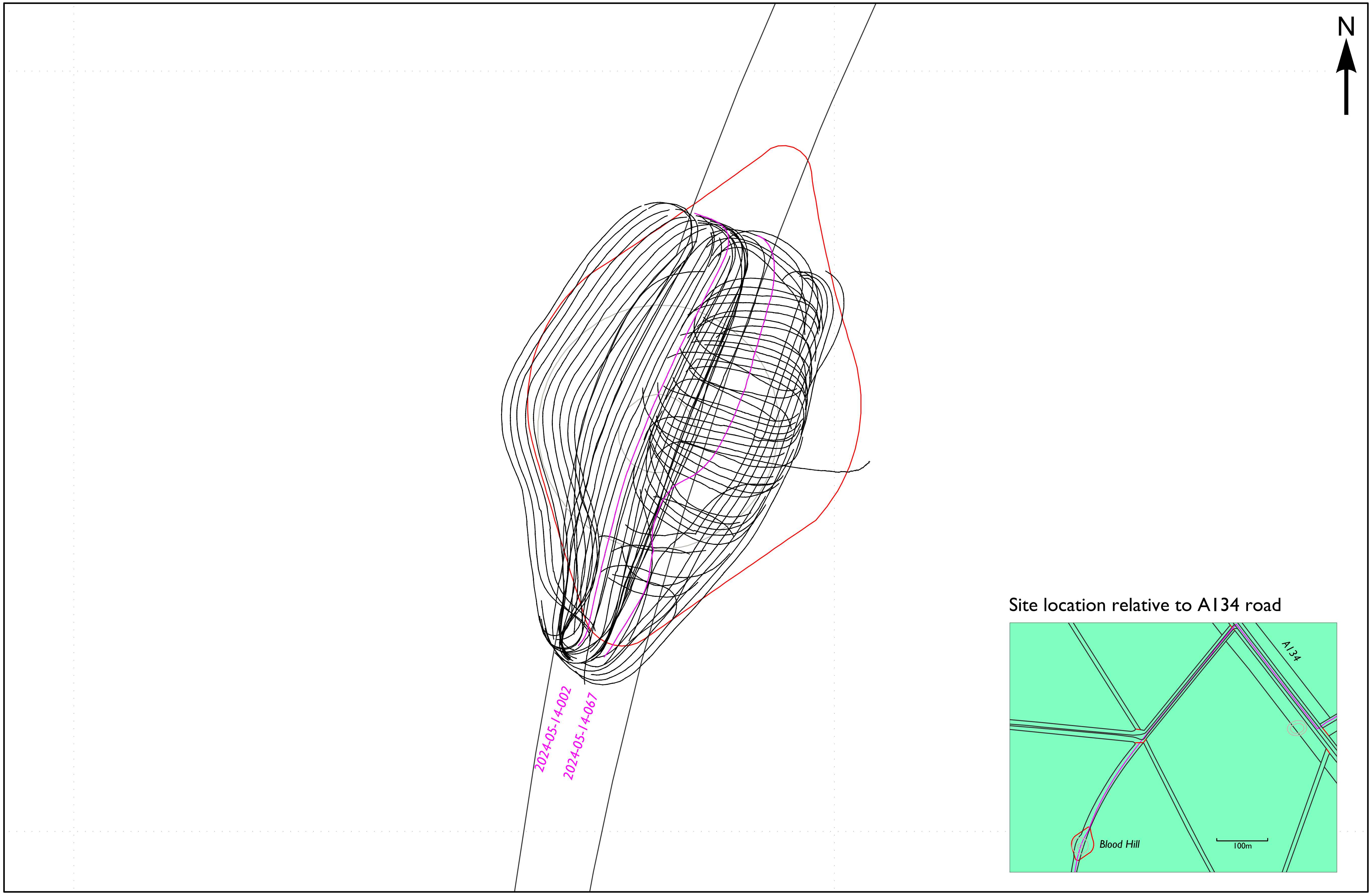
Figure 1

BLOOD HILL BARROW, LYNFORD AND THETFORD, NORFOLK

Location of GPR instrument swaths, May 2024

TL8487



0 30m
1:500

extent of scheduled monument

Ground Penetrating Radar survey swaths

2024-05-14-001 Location of selected GPR profiles shown on Figure 6

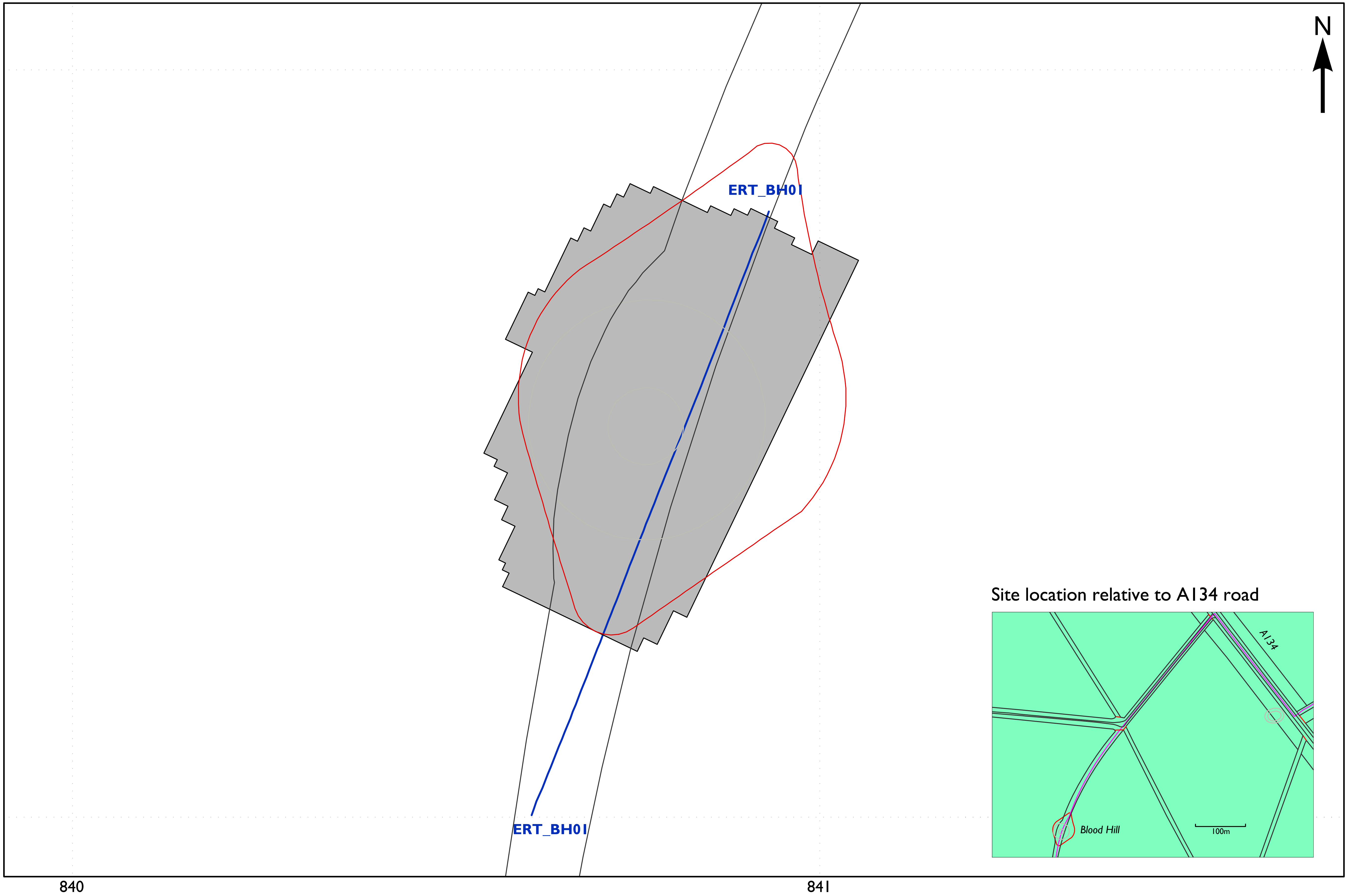
Geophysics Team 2024

Historic England

Figure 2

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK

Location of earth resistance and ERT surveys, May 2024



0 30m
1:500

extent of scheduled monument
extent of earth resistance survey
line of ERT traverse

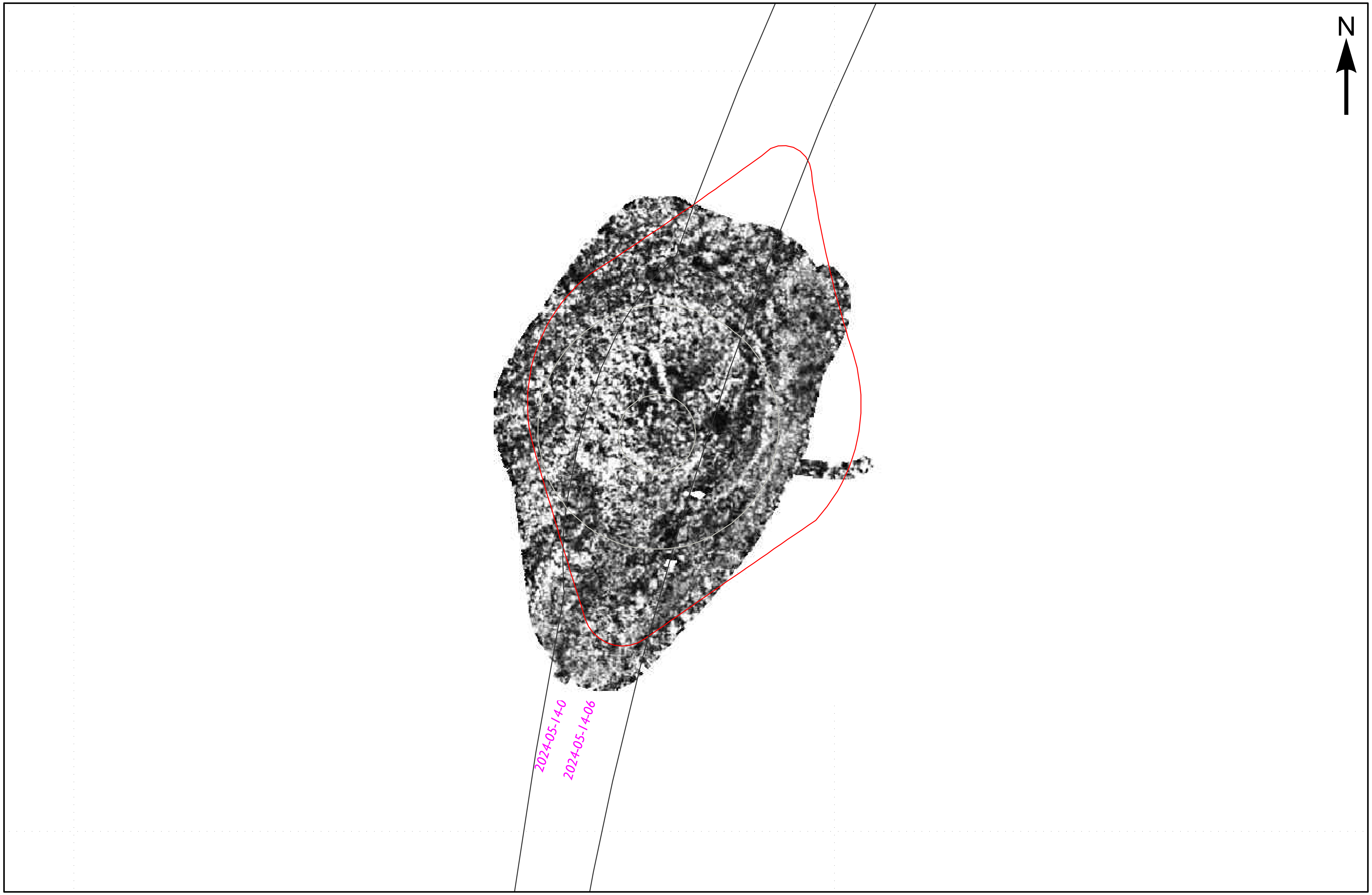
Geophysics Team 2024

Historic England

Figure 3

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK

GPR amplitude time slice between 22.5 and 25.0ns (1.09 to 1.21m), May 2024



0 30m
1:500

extent of scheduled monument

Low High
relative reflector strength

2024-05-14-001 Location of selected GPR profiles shown on Figure 6

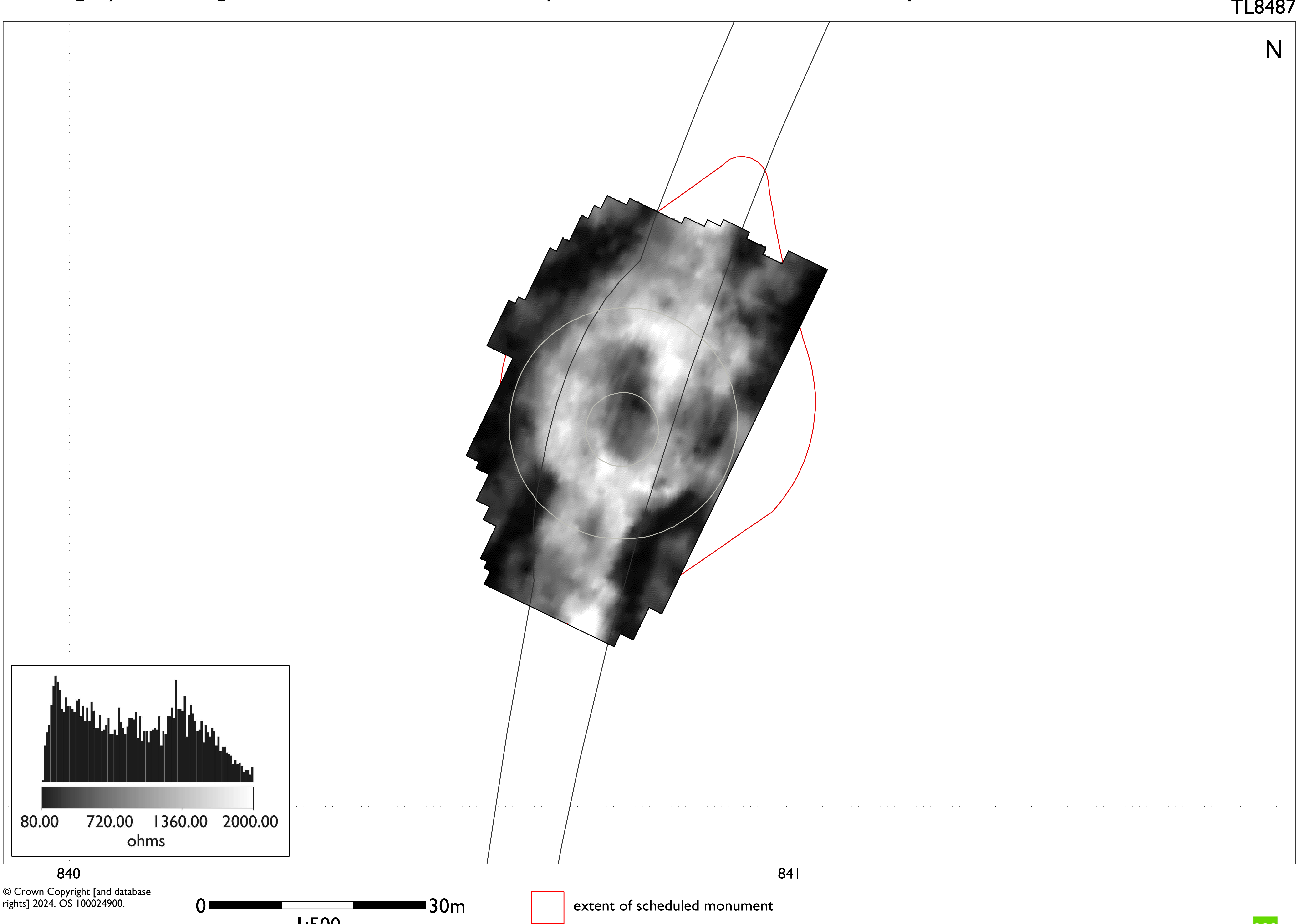
Historic England

Geophysics Team 2024

Figure 4

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK

Linear greyscale image of 0.5m mobile electrode separation earth resistance data, May 2024

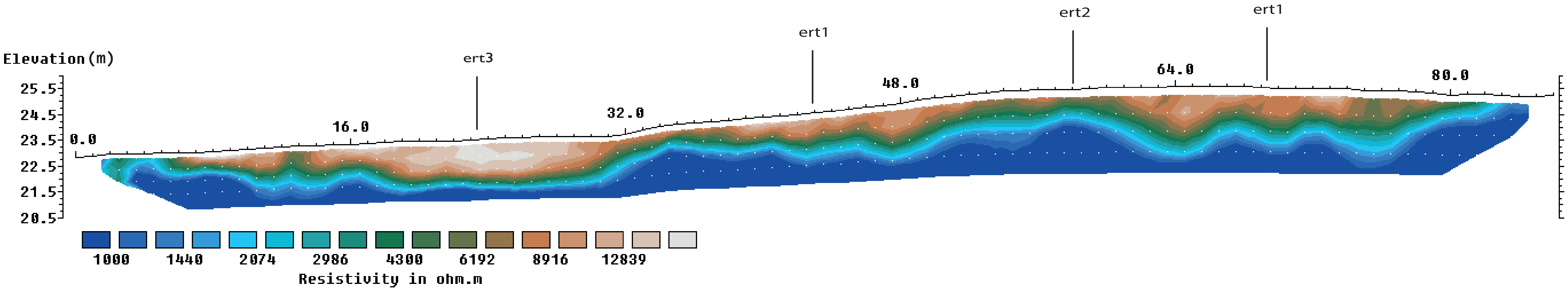


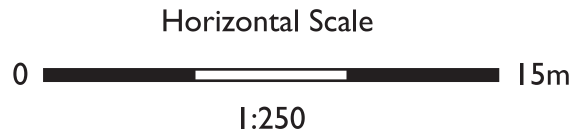
Geophysics Team 2024

Historic England

Colour-scale image of ERT output resistivity model profile, May 2024 (vertical exaggeration x 1.5)

ERT_BH01: 87m long SW to NE section annotated with significant anomalies ert1-3 (absolute error between model and field measurements = 4.7%)

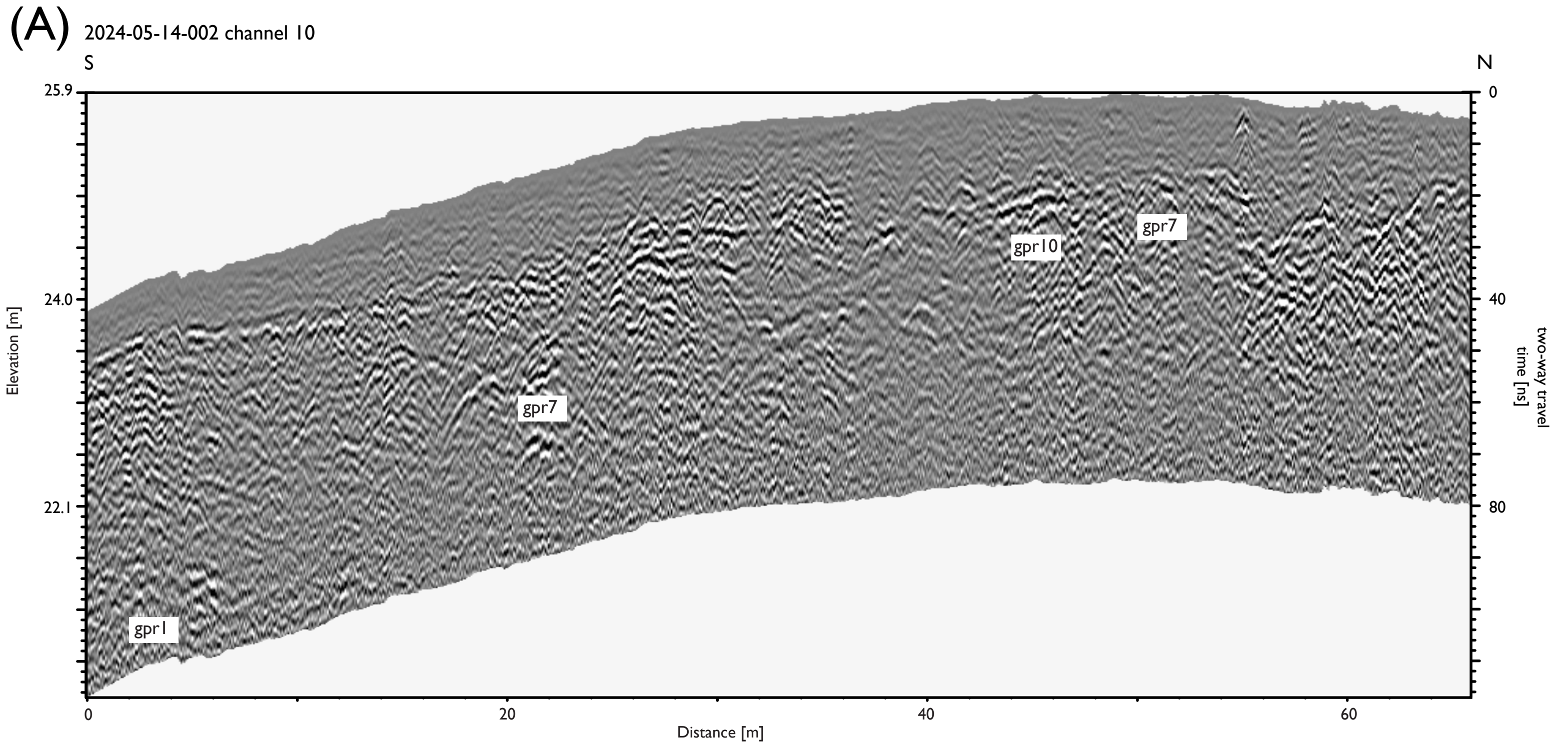


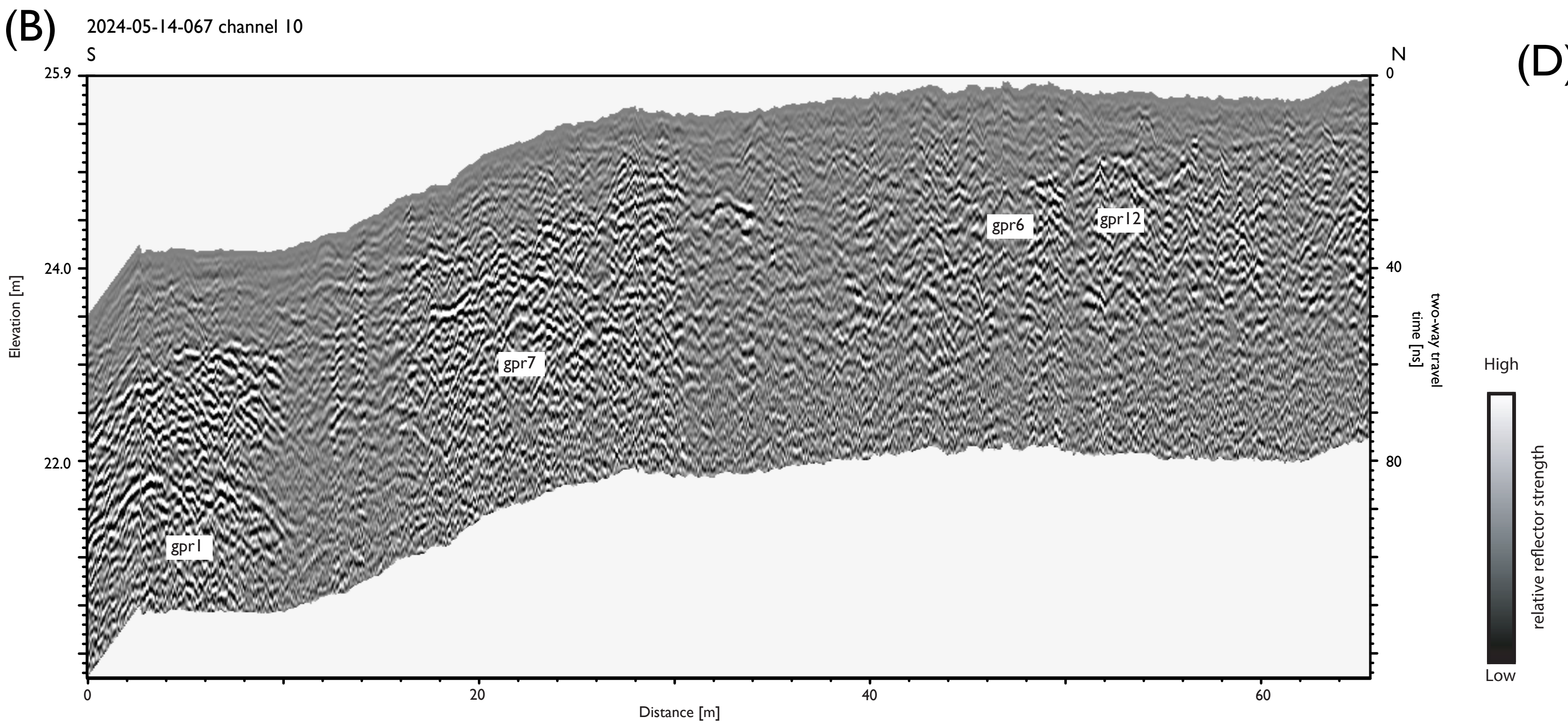


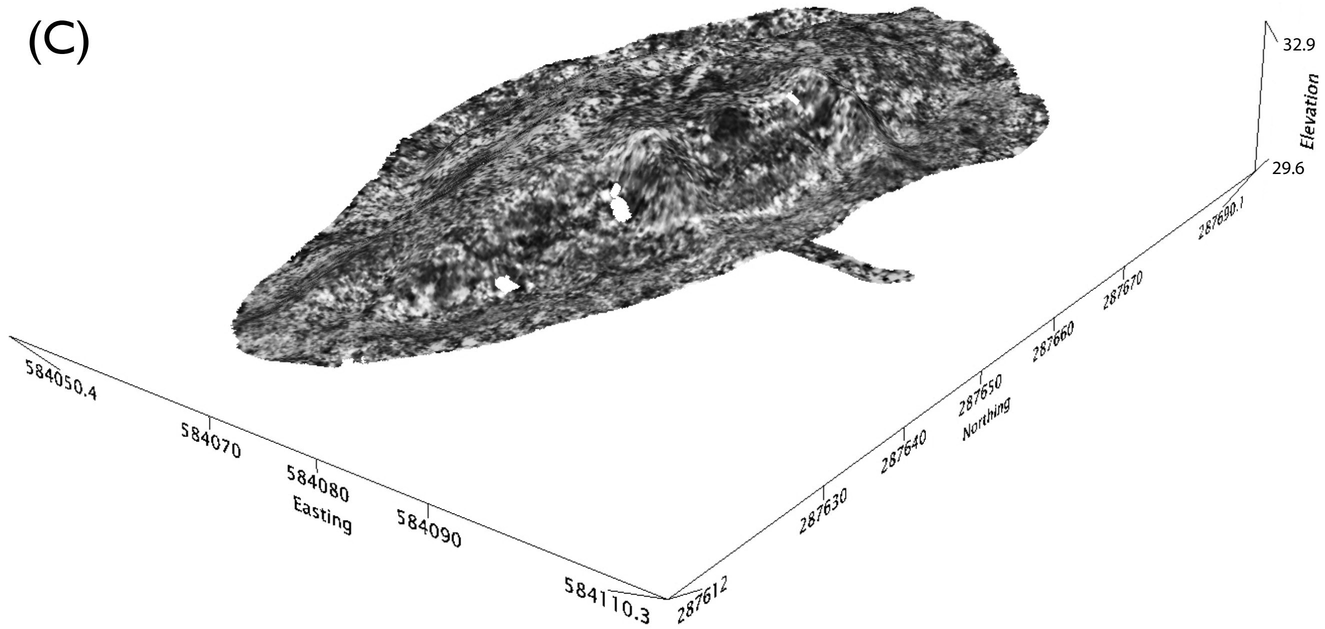
BLOOD HILL, LYNFORD AND THETFORD, NORFOLK

Representative topographically corrected GPR profiles and time slice, May 2024

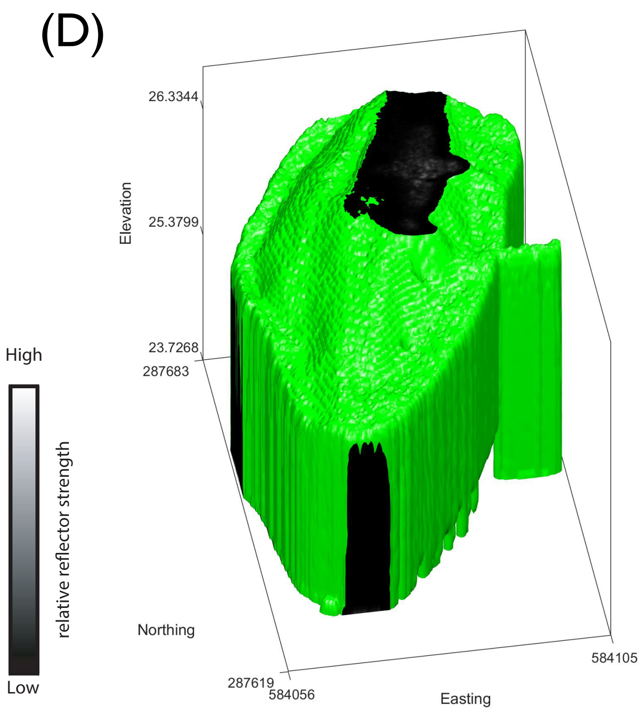
Figure 6

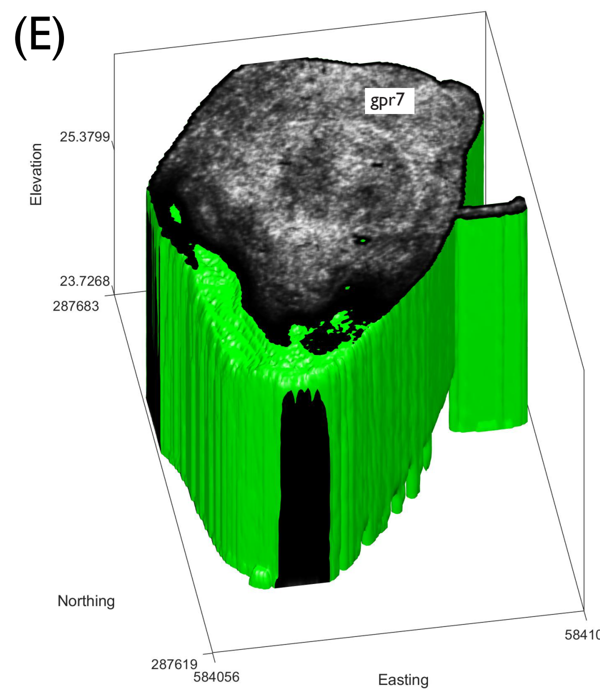






GPR time slice between 22.5 and 25.0ns (1.09 to 1.21m) draped over a Digital Terrain Model (DTM) of the site with a vertical (elevation in m above ODN) exaggeration of x 5. Eastings and Northings given in OS NGR coordinates.

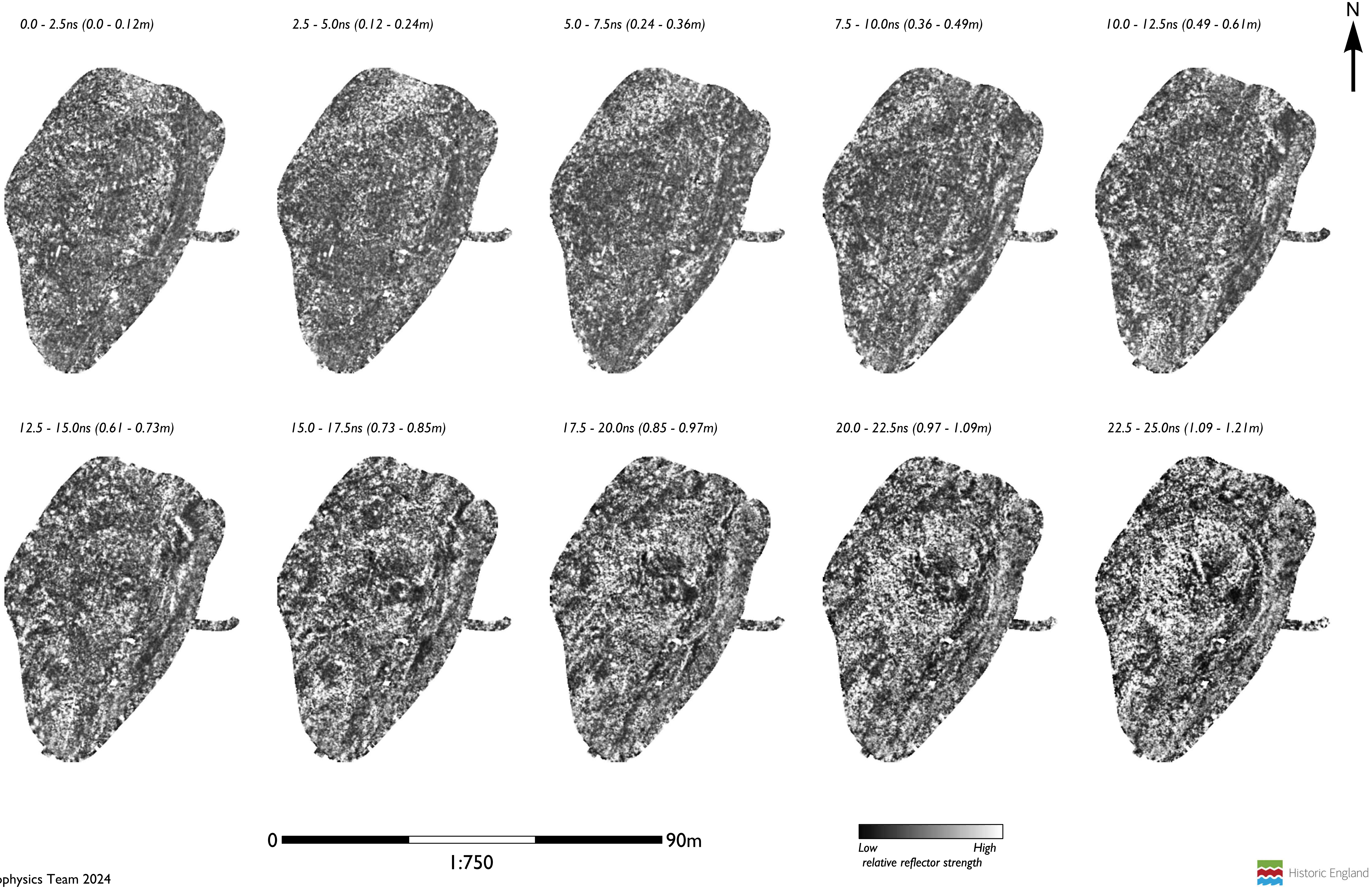




GPR cut-away model showing full topography (D) and data cut-away (E) to an elevation of 24.7m with a vertical (elevation in m above ODN) exaggeration of x 4. Eastings and Northings given in OS NGR coordinates.

Figure 7

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
GPR amplitude time slices between 0.0 and 25.0ns (0.0 to 1.21m), May 2023



Geophysics Team 2024

Figure 8

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
GPR amplitude time slices between 25.0 and 50.0ns (1.21 to 2.43m), May 2023

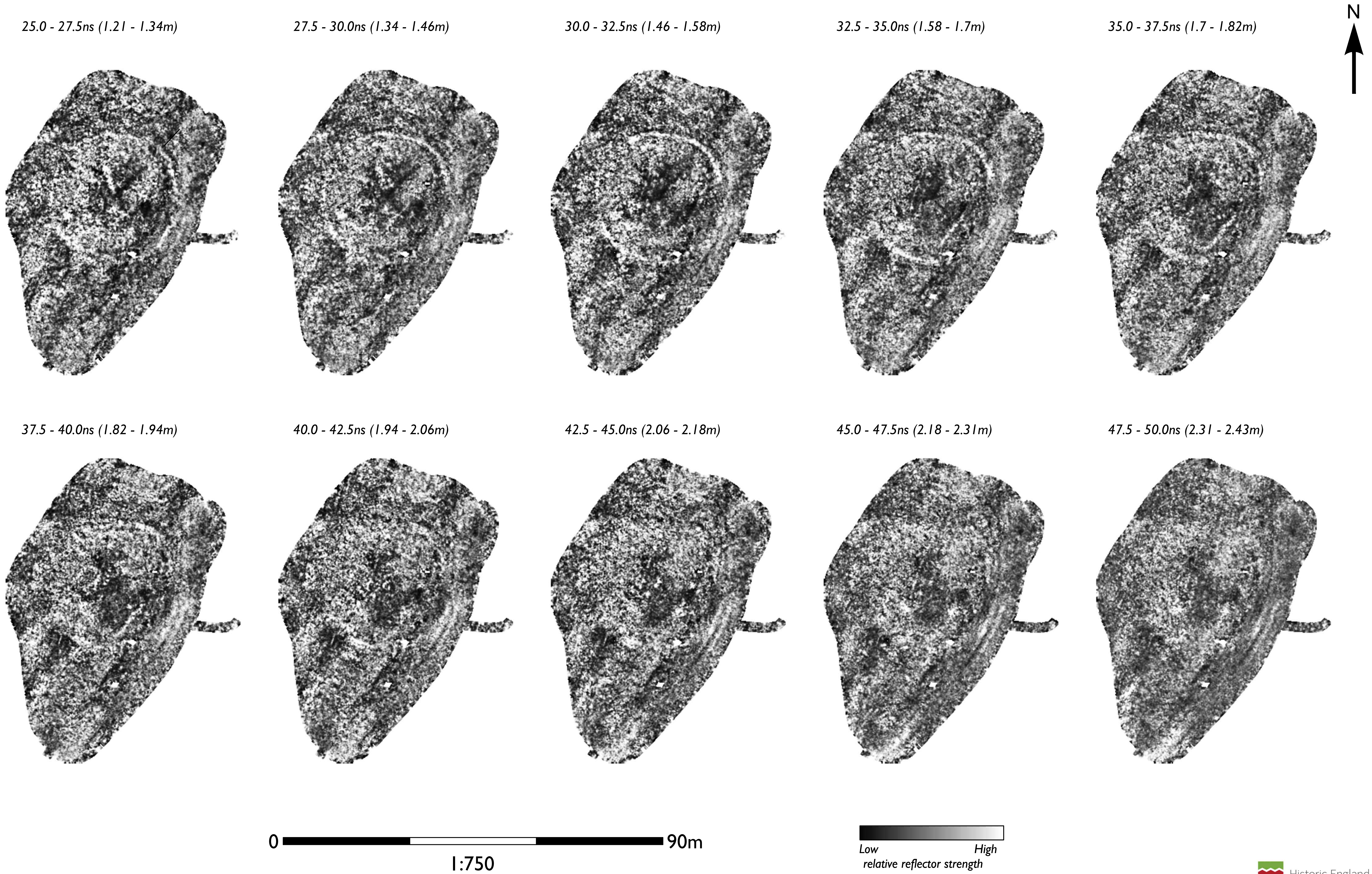


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Figure 9

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
GPR amplitude time slices between 50.0 and 75.0ns (2.43 to 3.64m), May 2023

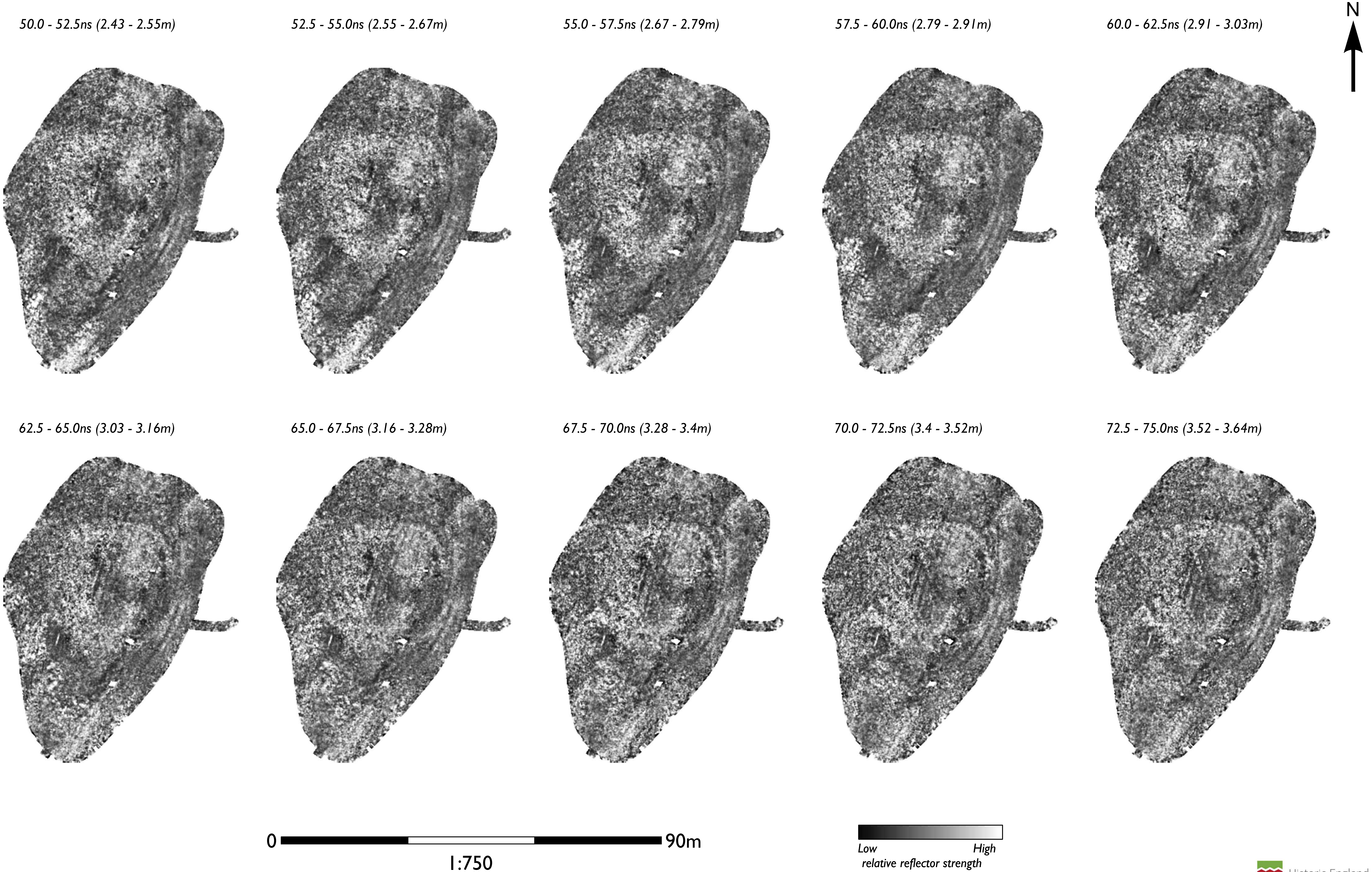

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Figure 10

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
Earth resistance survey, May 2024

N

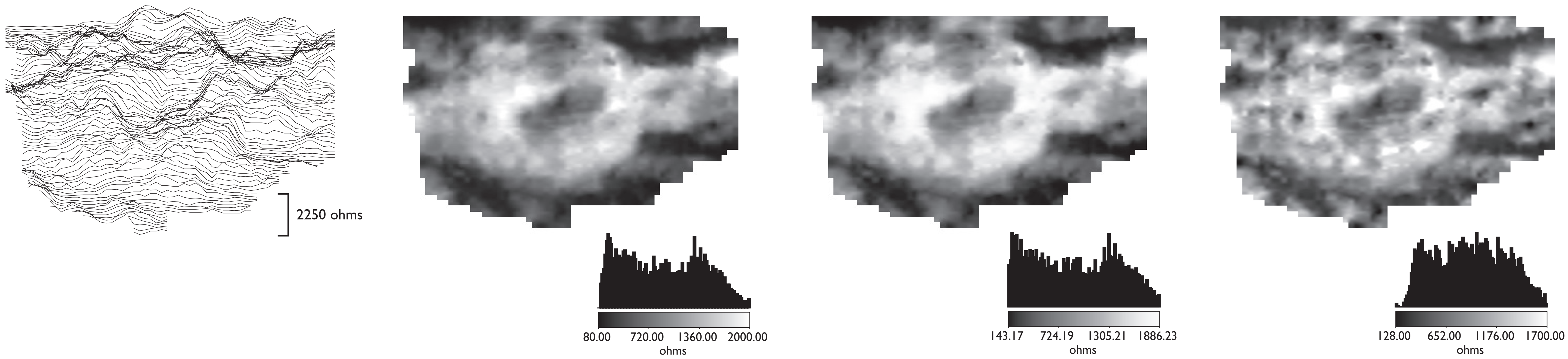
0.5m mobile electrode separation data

(A) Trace plot of minimally processed data

(B) Linear greyscale image of minimally processed data

(C) Histogram equalised greyscale image of minimally processed data

(D) Linear greyscale image of Wallis contrast-enhanced data



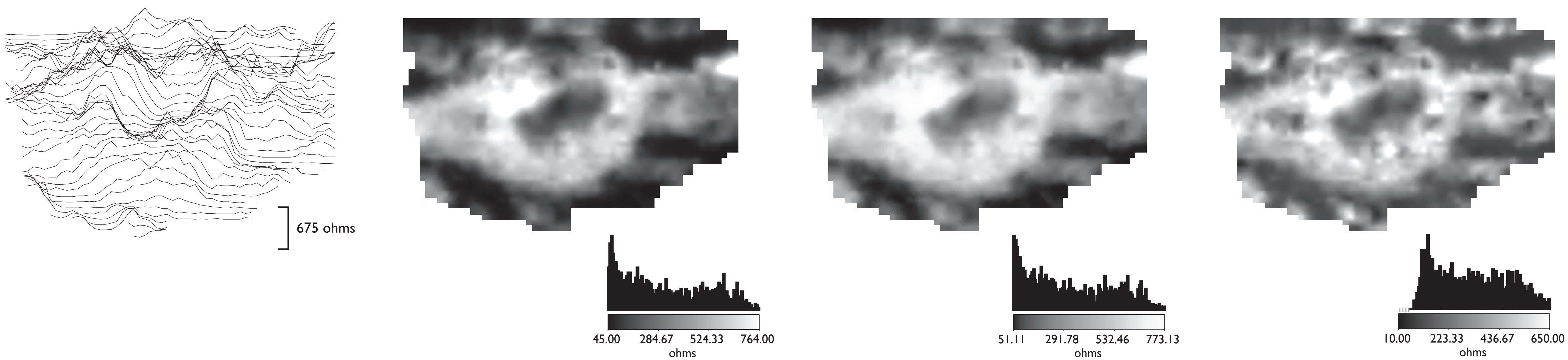
1.0m mobile electrode separation data

(E) Trace plot of minimally processed data

(F) Linear greyscale image of minimally processed data

(G) Histogram equalised greyscale image of minimally processed data

(H) Linear greyscale image of Wallis contrast-enhanced data



0 60m

1:750

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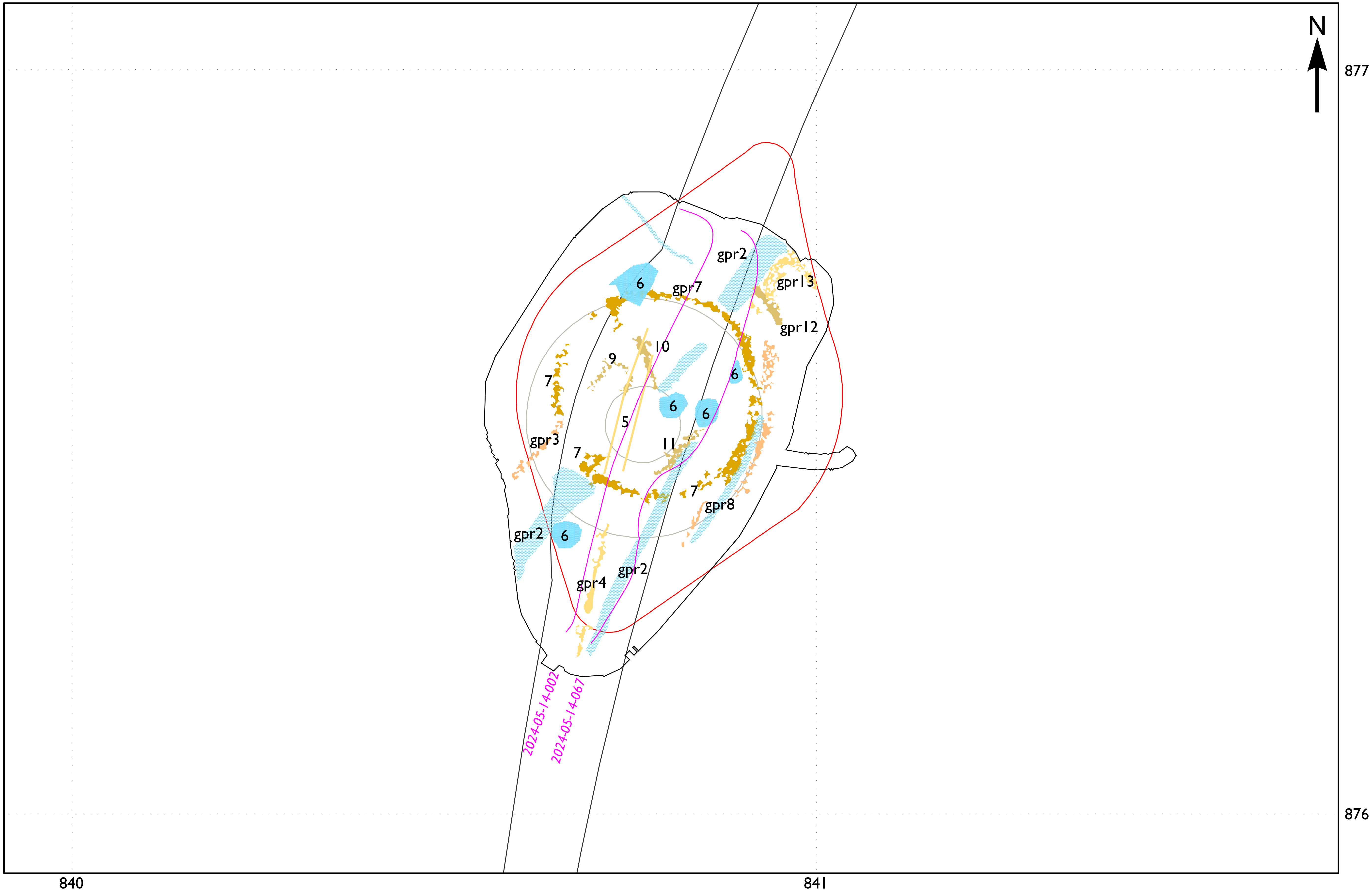
BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
Graphical summary of significant GPR anomalies, May 2024

TL8487



0 30m
1:500

extent of scheduled monument
low amplitude reflectors
high amplitude reflectors
anomalies of known or recent origin
2024-05-14-001 Location of selected GPR profiles shown on Figure 6

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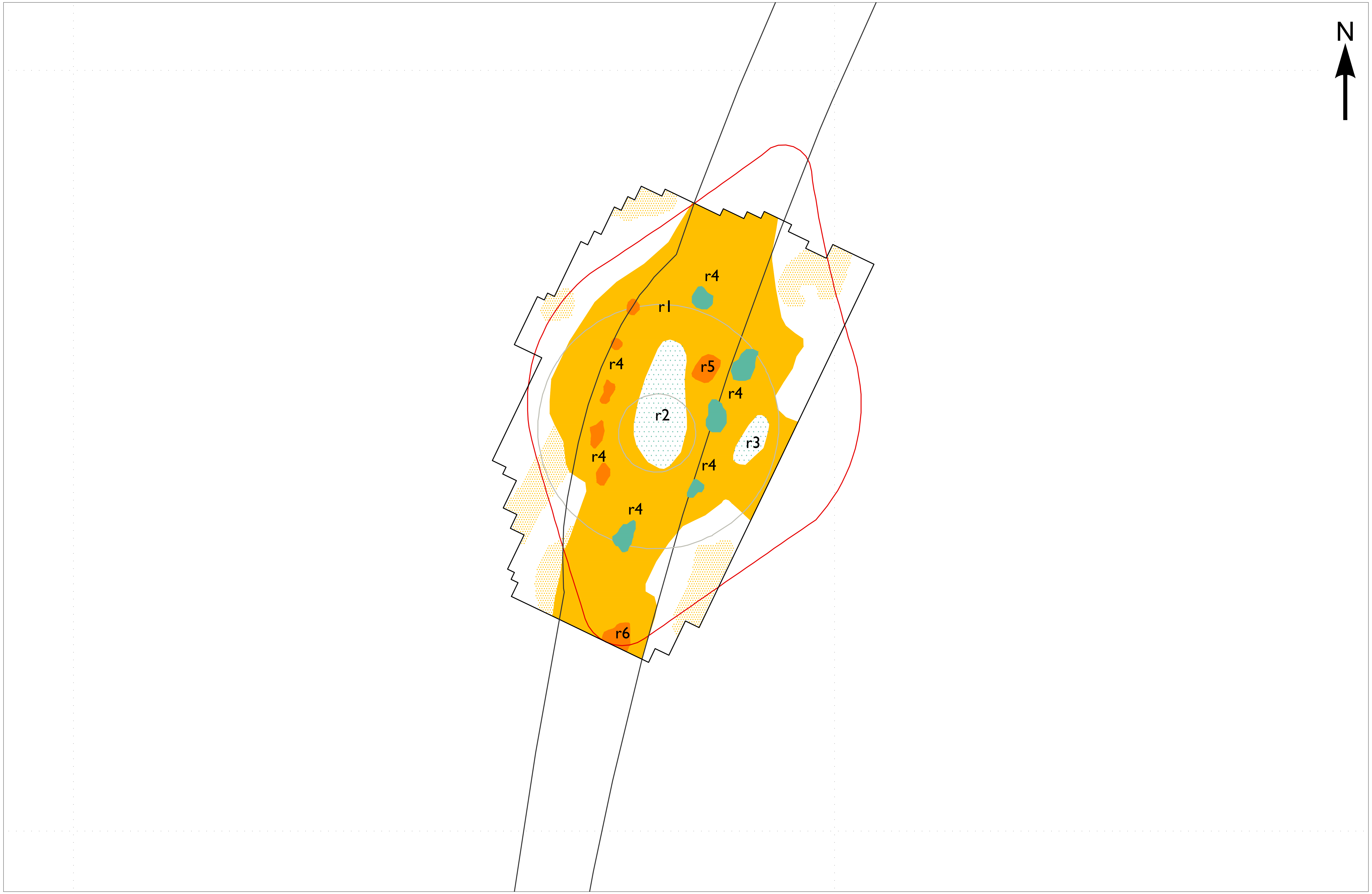
Figure 12

BLOOD HILL, LYNFORD AND THETFORD, NORFOLK
Graphical summary of significant earth resistance anomalies, May 2024



0 30m
1:500

extent of scheduled monument
very high resistance
high resistance
low resistance

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