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SILBURY HILL, WILTSHIRE
REPORT ON GEOPHYSICAL SURVEYS, 2005-2008

Neil Linford, Paul Linford, Louise Martin and Andy Payne

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SUMMARY

A series of geophysical survey visits were made between February 2005 and February 2008, to investigate the immediate environs of Silbury Hill, Wiltshire. The initial impetus for the survey was to assist with the location of a works compound required for remedial repairs to the monument, begun in 2007, following the partial collapse of earlier investigative tunnels dug into the hill. The survey area covered with a high-sensitivity caesium magnetometer array was subsequently expanded and successfully revealed a wealth of archaeologically significant anomalies, including what appears to be a larger Roman settlement at the site than had previously been recognised. Additional areas of earth resistance and ground penetrating radar were also conducted to investigate specific anomalies, some thought to be masonry buildings. Finally, an attempt was made to profile sections through the ditch surrounding the monument with a combination of earth resistance tomography and radar transects.

CONTRIBUTORS

The field work was conducted by Neil Linford, Paul Linford, Louise Martin and Andy Payne with assistance in May 2006 from Rebecca Briscoe (MA placement student, University of Oxford).

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ARCHIVE LOCATION

Fort Cumberland.

DATE OF FIELDWORK AND REPORT

The fieldwork was conducted during the following seven weeks: 21-25th February 2005, 13-17th March 2006, 15-19th May 2006, 16-20th October 2006, 23-27th July 2007, 24-28th September 2007 and 11-15th February 2008. The report was completed on 21st January 2010.

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CONTENTS

INTRODUCTION

Following the partial collapse of earlier investigative tunnels dug into Silbury Hill (SAM Wilts. 21707) from the C18th onwards, coincident with a period of very wet weather between 1999 and 2000, the future stability of the monument was threatened. Remedial engineering works were planned by English Heritage to backfill voids within the structure and geophysical survey was requested to assist with the siting of a suitable compound and access route to the hill (Harding 2005; McAvoy 2006). This initial phase of survey proved successful, especially the results from high sensitivity caesium magnetometer coverage that revealed quite subtle anomalies over the areas of alluviated flood plain flanking the river Kennet (Payne *et al.* 2006). The geophysical campaign was therefore extended, over 7 visits, to produce a total area of 30.6ha of magnetic survey, augmented by additional area earth resistance (5.5ha) and ground penetrating radar (GPR) coverage (2.1ha).

The wider aim of the geophysical survey then became the investigation of the immediate environs of the monument, particularly in areas where visibility through more conventional means, such as surface artefact recovery and aerial photography, has been compromised by the depth of alluvial overburden. This extended the scope of the survey to cover areas of arable land and water meadow to the S of the A4, reaching just beyond the present source of the river Kennet at the Swallowhead springs. In addition, a series of radial transects crossing the ditch surrounding the monument were investigated using a combination of earth resistance tomography (ERT) and GPR. The aim of this work was to obtain an estimate of the original ditch profile that is now largely obscured by infill and alluvial deposits. Field (2002) provides an excellent summary of archaeological knowledge surrounding Silbury, including a recent analytical survey of the monument and details of perhaps the first geophysical investigations at the site, an unsuccessful earth resistance survey of the mound (McKim 1959).

The site (centred on SU101685) lies mainly on shallow loamy soils of the Frome association (Soil Survey of England and Wales 1983) developed over Cretaceous Middle Chalk, with the monument itself apparently situated on valley gravel (Institute of Geological Sciences 1974). Alluvial deposits have accumulated over the flood plain of the Winterbourne, which bounds the lower-lying areas of the site, skirting the outcrop of gravel immediately E of Silbury Hill. A slightly raised plateau in the water meadow to the S of the A4 may be due either to an extension of the gravel or, perhaps, a spur of middle chalk from Waden Hill. The majority of fields were down to grass, for the most part un-grazed, although a hay crop was taken from the water meadow used for pasture to the S of the A4. Magnetic survey in the large arable field was conducted in spring 2007 when the field was down to a cereal crop, followed by GPR coverage in autumn after the harvest when the field lay fallow. As would be expected, weather conditions varied over the survey campaign and included periods following quite substantial rain fall when localised water logging occurred over low lying areas where the river had flooded its banks.

METHOD

Temporary grids were established in the field for the survey with a Trimble real-time kinematic Global Positioning System (GPS).

Magnetic survey

Caesium magnetometer

The magnetometer survey was conducted using an array of four specially modified high sensitivity Scintrex SM4 caesium vapour sensors, mounted on a non-magnetic cart system. Readings were collected over the grids shown on Figure 1 at a sample interval of 0.125m along 100m, N-S orientated traverses separated by 0.5m.

Post-acquisition processing included the application of a windowed, high-pass median filter to reduce sensor drift due to the diurnal variation of the earth's magnetic field and any directional sensitivity of the sensors. The median filter was applied with a radius of 20m or 30m parallel to the survey lines, depending on the rate of drift evident, and a cross-line window of width 5m or 10m was also used to preserve anomalies running parallel to the traverse direction. In addition, the total magnetic field measurements have been transformed to a 1m pseudo-gradient data set by upward continuation then subtraction from the original (Blakely 1995; Tabbagh *et al.* 1997). Finally, any obvious mismatch between adjacent blocks of survey data was corrected by applying a 1D high-pass median filter of window width 10m to columns of data parallel and in close proximity to the mismatched grid edge and the original values replaced with a linearly weighted combination between these and the edge matched version.

Fluxgate magnetometer

Total field magnetic measurements collected close to the course of the A4 were adversely affected by a combination of passing traffic and intense ferrous disturbance from the route of a pipeline to the S of the road. Two survey areas close to the road (Figure 1) were therefore also surveyed with a Bartington Grad601 dual sensor fluxgate gradiometer. Although slightly less sensitive than the caesium sensors, the gradiometer configuration of this instrument should reduce the influence of the ferrous disturbance (Linford *et al.* 2007). Readings were collected at a 0.25m sample interval along, parallel, NS orientated traverses spaced 1.0m apart using the 200 nanotesla per metre (nT/m) range setting of the instrument. Subsequent processing of the data involved initial truncation to exclude extreme readings (values above and below 100 nT/m) caused by ferrous disturbance. The directional sensitivity and drift correction of the sensors was then reduced by setting each instrument traverse to a zero median value (English Heritage 2008). The resulting fluxgate data sets were then interpolated to match the sample interval of the caesium survey and combined with the pseudo-gradient transformation of the total field measurements.

A linear greyscale image of the combined magnetic survey is shown at a scale of 1:4000 superimposed over the base Ordnance Survey mapping in Figure 2, together with similar sub-plots at a larger scale of 1:2500 in Figures 3 and 4. The data is also shown as greyscale images and traceplots in Figures 5 and 6, for areas to the N of the A4, and Figure 7 and 8 for coverage to the S, following the removal of intense near-surface ferrous responses and truncation of the data set values between +/-20 nT/m (Scollar *et al.* 1990, 492).

Earth resistance survey

Selected areas covered by the magnetometer survey were chosen to survey with earth resistance to provide complementary coverage. For the most part, the twin electrode configuration was used for the survey, although two trial areas were surveyed using a square array, wheeled resistance cart.

Twin electrode

Measurements of Areas B, C and Di (Figure 1) were collected with a Geoscan RM15 resistance meter and a PA5 electrode frame in the twin electrode configuration, following the standard method outlined in note 1 of Annex 1, with readings taken at 1.0m along parallel traverses separated by 1.0m using a 0.5m mobile electrode spacing. The survey in Areas E-H was conducted with a MPX15 multiplexer and an adjustable PA20 electrode frame, to allow readings to be collected simultaneously at both a standard 0.5m and a more deeply penetrating1.0m mobile electrode spacing. Sample intervals of 0.5m x 1.0m or 1.0m x 1.0m were used for the 0.5m and 1.0m mobile electrode separations respectively.

Post-acquisition processing of the twin electrode data included the application of a 2m by 2m thresholding median filter to remove isolated high readings caused by poor contact in Areas E-H (Scollar *et al.* 1990, , 492). Discontinuities between grid edges were reduced by modifying the statistical distribution of adjacent data sets (Area G) or applying a similar edge matching routine to that described above for the magnetic survey (Areas E and G). Further data processing to enhance linear anomalies from the background variation included the application of either a Guassian high-pass filter, with a radius of 3m (Areas B, E and H), 5m (Areas C and Dii) or 7m (Area G), or for Area G a Wallis contrast enhancement algorithm with a radius of 5m (Scollar *et al.* 1990, 506-12). A regular, surface agricultural pattern in Area H was suppressed by the application of a directional cosine filter in the frequency domain (Geosoft 1993, 20-1) and near-surface anomalies from both Area H and F were further enhanced by subtracting the deeper penetrating 1.0m mobile probe spacing results from the 0.5m data.

The final processed twin electrode results are presented as greyscale images superimposed over the OS mapping on Figure 9, with additional versions of the minimally enhanced raw and processed versions of the data shown as both greyscale images and traceplots on Figures 10 to 14.

Square array

The survey was undertaken with a Geoscan RM15 resistance meter and MSP40 wheeled square array system, using an electrode separation of 0.75m over Areas A and Dii (Figure 1). Whilst there are many possible arrangements for the current injection and potential measurement electrode pairs available with the square array, only two of these are independent: known as the alpha and beta configurations, from which all other geometries can theoretically be derived (Aspinall and Saunders 2005). As the alpha and beta configurations are each slightly directionally sensitive, both are required to accurately map all subsurface anomalies. In this case, the MSP40 system was configured to take measurements at 0.25m intervals along parallel traverses separated by 1.0m, alternating between alpha and beta electrode configurations.

The two resulting datasets were treated independently and subject to minimal processing including: replacing all erroneous earth resistance measurements of less than 0 Ω with null values; and then correcting the offset in measurement position between the two electrode configurations by shifting traverses of the alpha data set longitudinally to maximise their correlation with the beta results.

The alpha and beta configurations were then combined to form a composite dataset for each survey area. This was achieved by first partitioning both the alpha and beta measurements into high and low spatial frequency components. The two sets of low frequency readings were averaged to produce a combined regional component while a combined local variation component was derived by selecting from one of the two high frequency components whichever value had the greatest absolute magnitude. The final output was produced by summing the combined regional and local variation components.

Figure 15 shows these combined square array data-sets presented as greyscale images superimposed over the OS mapping. In addition, the minimally processed alpha and beta raw survey results are shown together with combined and processed versions of the same data on Figures 16 and 17.

Ground Penetrating Radar (GPR) survey

Area survey

The GPR survey was conducted over the location of the masonry buildings identified by the initial magnetic survey in the arable field to the S of the A4 with a Sensors and Software Pulse Ekko PE1000 console and a 450MHz centre frequency antenna, selected after field trials that suggested this would obtain the optimum depth of penetration and lateral resolution required to image the expected archaeological targets. An average subsurface velocity of ~0.077m/ns, determined from analysis of a common mid-point (CMP) gather, was also adopted as a reasonable average value for processing the data from the site and for the estimation of depth to reflection events in the recorded profiles.

Data was collected along parallel NW traverses separated by 0.5m (Figures 1 and 18). Individual traces along each profile were separated by 0.05m and recorded the amplitude of reflections through a 40ns time-window (Figure 19). Post acquisition processing involved the adjustment of time-zero to coincide with the true ground surface, removal of any low frequency transient response (dewow), noise removal and the application of a suitable gain function to enhance late arrivals.

Owing to antenna coupling between the GPR transmitter and the ground to an approximate depth of $^{\lambda}/_{2}$, very near-surface reflection events should only be detectable below a depth of 0.09m if a centre frequency of 450MHz and a velocity of 0.077m/ns are assumed. However, the broad bandwidth of an impulse GPR signal results in a range of frequencies to either side of the centre frequency which, in practice, will record significant near-surface reflections closer to the ground surface. Such reflections are often emphasised by presenting the data as amplitude time slices. In this case, the time slices were created from the entire data set, after applying a 2D-migration algorithm, by averaging data within successive 2ns (two-way travel time) windows (Linford 2004). Each resulting time slice, illustrated as a greyscale image in Figures 20 and 21, represents the variation of reflection strength through successive ~0.077m intervals from the ground surface. Figure 18 shows a representative amplitude time slice, between 18 and 20ns, superimposed over the base OS mapping.

Transect survey

A series of 12 GPR profiles were collected along radial transects across the ditch surrounding the base of the monument and the apparent extension to the W (Figure 1). Due to the level of signal attenuation expected within the high conductivity ditch fill, the profiles were collected with both 225 and 110MHz centre frequency antennas to maximise the depth of penetration. Readings were collected at 0.05m intervals through a 100ns time window with the 225MHz antenna and at 0.5m intervals through a 150ns time window with the lower frequency 110MHz antenna. An average subsurface velocity of ~0.075m/ns for the near-surface sediments, was determined from analysis of a common mid-point (CMP) gather collected with the 110MHz centre frequency antenna. This velocity was adopted as a reasonable average value for processing the data from the site and for the estimation of depth to reflection events, given in units of absolute elevation for direct comparison with the corresponding ERT transects (Figures 22 and 23).

ERT transects

Each ERT transect was laid out along one of the lines used for the GPR profiles but, owing to the greater acquisition time for each ERT data set, 7 electrical sections were laid out around the base of the hill, 6 aligned radially outwards from its centre across the encircling ditch and a seventh over the extension to the W (Figures 1, 22 and 23). A 50 electrode Campus Geopulse system was used with electrodes arranged linearly at a separation of 1m. Precise electrode positions and elevations were established with a differential kinematic GPS system and the Wenner electrode configuration was used to collect the earth resistance measurements. The sections were inverted and plotted using Geotomo Ltd's Res2DInv software version 3.55.

RESULTS

Magnetometer survey

Graphical summaries of the anomalies discussed in the following text, superimposed over the base OS map data, are provided in Figures 24 and 25.

Modern disturbance

The most obvious modern disturbance is found along the course of the strategic oil pipeline [Figure 25: m1] that runs immediately S of the A4. This intense anomaly produces a 30m wide zone of magnetic interference that increases substantially to the W in the large arable field, where the pipeline appears to branch along a number of divergent courses (Gunter and Vaughan 2005, Figure 60). This field also contains a N-S orientated track way [m2] running S from the A4, apparently formed from magnetic rubble. It is known to have been in use within living memory and recorded on the historic mapping (OS Historic County Mapping Series: Wiltshire, 1886). There is also evidence for a network of ceramic field drains [m3] across the lower-lying ground in the water meadow.

To the N of the A4 extensive spreads of intense magnetic disturbance [Figure 24 m4-5] have been recorded coinciding with the course of a former, possibly rubble filled, drainage channel marked on the OS mapping. In addition, an alignment of four intense anomalies [m6] may, possibly, be related to either a former boundary or the garage formerly located in the Silbury viewing area car park. A more curious linear magnetic anomaly is found at [m7] and demonstrates a consistent, moderately intense dipolar response (>5nT/m) with the negative lobe displaced to the S. This area was also covered by an experimental survey conducted with a very high sensitivity instrument using a low temperature Superconducting Quantum Interference Device (SQUID) operating in an intrinsic short baseline (0.04m) horizontal gradiometer configuration (Institut für Physikalische Hochtechnologie 2007; Schultze *et al.* 2007; Schultze *et al.* 2008). Due to the much higher bandwidth of this instrument compared to caesium sensors (1000 versus 10Hz), the dominant spectral component of [m7] could be isolated and was found to peak between 45 and 55Hz. This unusual response is highly suggestive of a live electricity cable carrying alternating, mains frequency current, although the function of this service is unknown and difficult to ascertain from the course of the anomaly described in the data.

Natural background variation

A number of anomalies found in the data appear to reflect the complex nature of natural deposits either as individual discrete responses or broader areas of magnetic variation. For example, to the E of Silbury Hill over the raised gravel plateau some areas of increased magnetic response [m8-12] are found together with a scatter of more pronounced positive anomalies [m13], which may well be related to geomorphological features on the flood plain. A similar pattern of apparently natural response [Figure 25: m14] is found at the foot of the chalk slope to the S of the A4 running along the valley bottom beyond the Swallowhead springs, although this is obviously inter-cut with more significant archaeological anomalies discussed below. An additional response to geomorphology occurs on the chalk ridge above the valley bottom, where a pattern of curvilinear and more amorphous positive anomalies [m15] may represent periglacial features in the underlying chalk (Ballantyne and Harris 1994, 125-7; Field 2002).

Significant anomalies to the N of the A4

A number of linear magnetic anomalies [Figure 24: m16] are superimposed on the broader natural variation and display a regular arrangement, suggestive of a group of rectilinear ditched enclosures, close to the course of the Mildenhall (*Cunetio*) to Bath (*Aquae Sulis*) Roman road (now the approximate route of the modern A4). An additional enclosure [m17] lies further E towards the river and contains a weakly defined, semi-circular anomaly [m18]. This area also includes a scatter of discrete positive magnetic anomalies [e.g. m19], that may indicate associated features, such as pits or quarries.

Towards the river the magnetic response becomes subdued due, no doubt, to the increasing depth of alluvial overburden. However, the high sensitivity of the caesium magnetometer survey has identified some very weak, ditch-type anomalies, such as [m20] possibly suggestive of a large polygonal enclosure. Other broad and perhaps natural linear anomalies [m21] extend through [m20] continuing W; and a group of large pit-type responses [m22] are present to the NW. Anomalies [m20] and [m22], together with the fragmented linear responses at [m23-24] closer to the river, all share a similar alignment to enclosure features and ditches recorded as crop marks on the adjacent flank of Waden Hill (Powell *et al.* 1996; Corney 1997). A further series linear magnetic anomalies [m25-27] may represent an additional enclosure system extending beyond the current survey area into the arable fields to the N, although some elements of this appear as negative anomalies perhaps associated with more recent ferrous disturbance.

The series of negative linear anomalies [m28-31] correspond to the location of slight depressions on the ground surface within the low lying area, and are likely to be more recent drainage channels.

A rather subdued magnetic response has been recorded over the areas where the magnetic coverage extends into the ditches surrounding the monument. This might be expected due to the infilling of the ditch with homogeneous water-lain sediments, although a concentration of ferrous detritus suggests more recent littering of the moat and the extension to the W.

Within the small paddock immediately E of the Winterbourne a positive ditch-type anomaly [m32] may, possibly, represent a previous diversion of the river. This would appear to be associated with a rectilinear, negative anomaly [m33] that suggests the location of masonry building remains.

Significant anomalies to the S of the A4

Given the location of the strongly magnetic pipe-line [Figure 25 m1] along the course of the Roman road in the vicinity of the other known archaeological activity previously reported in this area (Field 2002), there seemed little prospect of magnetic survey producing particularly fruitful results. It was therefore quite remarkable when, beyond the shadow of interference from [m1], a network of ditch-type anomalies [m34-36] was revealed forming three contiguous blocks of enclosures separated by two EW track-ways [m37-38], suggestive of an extensive Romano-British settlement aligned along a N-S trackway following the valley bottom to the Swallowhead springs. The results suggest the enclosure ditches may also extend upslope to the W beyond the recent trackway [m2] although further survey would be required to confirm this.

There is evidence of occupation throughout most of the complex in the form of sub-divided partitions and discrete pit-type anomalies, together with three rectilinear negative responses [m39-41] most likely to represent masonry-built structures. Two of the probable buildings [m39] and [m40] appear to be rectangular structures (10m x 6m and 13m x 10m respectively) similar to the rammed chalk foundations of the buildings recorded to the W of the Kennet at the bottom of Waden Hill (Powell *et al.* 1996, 31-4). However, [m41], found towards the centre of the enclosure system, is of greater extent (16m x 22m) and is suggestive of a more elaborate building, containing both internal divisions and a series of discrete positive anomalies that may represent thermoremanent features such as hearths or even a hypocaust.

Significant anomalies within the water meadow

Immediately E of the enclosures in the arable field there is a pronounced break in slope falling onto a low-lying water meadow by the river. A number of broad, weak curvilinear anomalies [m42], possibly of fluvial origin and similar to the magnetic response [m14], extend along the valley bottom to the S of the Swallowhead spring. Two large discrete anomalies [m43] may possibly represent large pits or natural features.

The tongue of raised ground in the water meadow is constrained by a series of wide curvilinear anomalies [m44] similar to [m42]. Although a natural origin seems most likely, it is not implausible that these represent deliberate ditches constructed, perhaps, to protect settlement on the raised area from flooding. An extant ditch is still visible around the raised ground, resolved as a narrow linear negative anomaly [m45] comprised of a series of angular sections. In places [m45] appears to be superimposed over [m44] suggesting, perhaps, a more recent origin designed to aid water management and drainage on the flood plain. However, a high density of anomalous activity, more suggestive of occupation, is centred on [m46] together with a pair of parallel linear anomalies [m47] that may represent a trackway extending N towards the A4.

A number of additional narrow linear negative anomalies [m48-51] together with a wider positive response [m52] seem likely to be more recent drainage channels, marked by visible linear depressions on the ground surface. Some circularity can, perhaps, be seen in the group of anomalies around [m48] but this interpretation is rather tentative and would benefit from further investigation through an extension of the earth resistance survey coverage. Anomaly [m49] partially correlates with the location of the enclosure identified by the earlier earthwork survey of this area (Field 2002, 39-40), although it appears as a negative response and may not be due to a ditch-type causative feature.

Earth resistance survey

A graphical summary of the anomalies discussed in the following text, superimposed on the base Ordnance Survey map data, is provided in Figure 26.

Natural background variation

The background response varied considerably between the different areas in terms of the range of measured values. This, in part, reflects the variation between the lower lying flood plain and the drier areas over the raised gravel. For example, the minimally processed raw data from Area Di illustrates the rapid change in background response, resolved as three apparent bands of values with the earth resistance decreasing as the land falls down towards the Winterbourne (Figure 17).

Significant anomalies

Area A (Figure 16)

This area targeted [m23] on the flood plain where a very low range of readings was recorded. There is some very tentative evidence for a group of low resistance linear anomalies and an area of noisier readings to the E, but these do not correlate with the magnetic response.

Area B (Figure 10(A) – (C))

Positioned on a levelled causeway across the ditch between the hill and the road, immediately below the portal to the 1968 tunnel, a curving area of high resistance [r1] is found that does not appear to reflect the local topography. This response, together with three low resistance linear anomalies to the E, are most probably related to either the variable compaction of spoil from the Atkinson tunnel deposited in this area or, perhaps, the animal water trough.

Area C (Figure 10(D) – (F))

Access to the 1968 tunnel portal for the remedial works was anticipated to cross this area of the ditch around the hill. As might be expected from the alluvial sediments within the ditch, the response is uniformly low with one higher resistance anomaly [r2] recorded at the edge. A further low resistance anomaly associated with [r2] may also be an edge effect from change in moisture levels between the ditch and the ground around it.

Area Di and Dii (Figure 10(G) – (I) and Figure 17)

This incorporates both the original twin electrode survey placed over an area of potential buildings (Area Di), previously reported in Payne *et al.* (2006), together with the results of the expanded coverage conducted with the MSP40 square array cart (Area Dii). There is a good correlation between the results from the two different arrays where these overlap.

A series of curvilinear high resistance anomalies [r3] are found to the W and these appear to cover approximately half the area of Dii. These higher resistance responses most probably reflect natural variations within the underlying gravel deposits and can be contrasted with the much lower values recorded to the E as the alluvial overburden increases towards the river. A high resistance linear response forming a circular arc at [r4] may be of greater archaeological significance, although it does not fully correspond with the enclosure ditches suggested by [m8] and [m16] in the magnetic data. The negative magnetic anomaly [m9] is also replicated in the earth resistance data as a more complicated area of low resistance [r5].

An intermediate band of background values [r6] separates the response over the higher ground [r3] from the flood plain and contains a weaker area of high resistance [r7], which broadly correlates with the area of the enclosure [m17] recorded in the magnetometer survey. Further to the E the background resistance falls to very low values, although two high resistance anomalies appear to relate to a buried drainage channel [r8] and a dry stream bed [r9] visible on the ground and mapped by the OS.

Area E (Figure 13)

A linear anomaly [r10] runs N-S through this small field to the E of the river joining with a rectilinear area of high resistance [r11] which appears better defined in the deeper penetrating 1.0m mobile probe spacing data (Figure 13(D) - (F)) and correlates with a negative magnetic response [m33] . This could potentially suggest that [r11] represents the remains of a building, perhaps buried at depth under waterborne deposits from the adjacent river. The Roman building remains revealed during the watching brief of the sewer pipeline immediately to the E are of interest, and suggestive of a Roman date for [r11] also. (cf Powell *et al.* 1996, Figure 10).

A linear low resistance anomaly [r12] follows the course of [r10] and is possibly associated with an intriguing alignment of discrete high resistance responses [r13]. The individual anomalies forming [r13] are of fairly uniform shape, about 2.5m wide and between 3 and 5m long, and could possibly relate to a deliberately placed line of large buried stones similar to the sarsen stepping stones laid across the Kennet to gain access to the Swallowhead Springs. The function of [r13] is difficult to ascertain, although it is possible that together with [r12] these represent a previous meander of the river or an attempt to control its course and prevent further eastward erosion to the E towards the site of the known Roman buildings. A more recent use of split sarsens to line the culverted course of the Beckhampton stream to the N of Silbury hill has been noted (Field 2002, 59) and a group of anomalies similar to [r13] are also found to the S of the A4 (see [r22] below). A high resistance linear response [r14] has been recorded adjacent to the road and whilst this might be an extension of [r10] (correlating with the ditch-type anomaly [m32]), its proximity to the modern course of the A4 may suggest a more recent origin. It is also possible that [r11] may represent the site of a water mill of indeterminate date taking water from a race defined by [r10] and rejoining the river through [r14].

Area F (Figure 11)

This small area was located over part of the strong ferrous disturbance in the magnetometer survey [m1] over the course of the known oil pipeline. Despite the low range of values, sufficient contrast was achieved to identify a low resistance anomaly [r15], which becomes more diffuse to the W especially within the 0.5m mobile probe separation data set (Figure 11(A) – (C)); and an adjacent high [r16] and low [r17] resistance to the S of [r15]. Although the magnetic data is highly disturbed in this area there is sufficient correlation to suggest that [r15-17] represent the course of the oil pipe line with the low resistance anomalies indicating, perhaps, a response to the trench rather than the pipe itself. The differing nature of anomalies [r16] and [r17] in the 0.5m and 1.0m mobile probe spacing data suggests the presence of two adjacent pipe lines, with the higher resistance response [r16] apparently closer to the surface. The more diffuse, low resistance response of [r15] as it approaches the Winterbourne to the W is also of interest and may suggest water-logging of the pipe trench rather than leaching of fuel oil from the pipe line.

A more tentative low resistance linear response [r18] is found further to the S running broadly parallel to [r15-17]. This appears less likely to be a pipe trench and is crossed by a subtle anomaly [r19], perhaps due to a more superficial surface feature.

Area G (Figure 14)

This field, to the S of the A4, was heavily waterlogged at the time of the survey and produced a very uniform response with minimal variation across the recorded readings. There is, however, a slightly higher response on the E side of the area [r20], parallel to the boundary with the river, possibly due to either the reinforcement of the banks or works related to the recent construction of new stock fencing. A similar but weaker response [r21] can be seen to the W and, although this runs parallel to the W boundary, it is offset into the field rather than adjacent to the edge. There is also a slightly raised linear response possibly crossing [r21] or perhaps a detached spur extending from it running to the W. Unfortunately, such low levels of contrast in the readings make these anomalies difficult to interpret, particularly when there is no apparent correlation with the magnetometer data from this area.

Area H (Figure 12)

The data collected over the raised ground in this field, possibly an island of valley gravel, were dominated by a large area of intermittent high resistance, bounded by a unit of three parallel linear responses following the break in slope: the first, [r22], is made up of regular-sized, discrete high resistance readings similar to [r13] and lies immediately in front of a low resistance ditch-type anomaly [r23], that is bounded by a second high resistance anomaly [r24] similar to [r23], but more continuous along its course. All three anomalies [r22-4] appear to define the edge of the raised ground to the N, W and S as a series of apparently deliberate angular sections. There is a much lower general response over the lower lying water meadow than on the raised ground. However, some banding is evident becoming fainter towards the river. This is similar to that in the magnetometer data [m42 and m45] and is possibly also related to fluvial activity. A few other slight anomalies have been recorded in this area, but none of these form any obvious patterning.

On top of the raised ground a low resistance linear anomaly [r25] extends from an intersection with [r23], and heads NE with a slight deviation towards its northern end. A low linear anomaly bounded by two high resistance responses [r26] runs parallel to [r25] and could, potentially, meet with [r22-4], but this area has not been completely mapped by the present survey coverage. To the W of [r25-6], numerous high and low linear striations [r27] appear to cross the area, but they do not form a completely regular grid-pattern and are difficult to interpret. There is some evidence for increased high resistance activity [r28], towards the S edge of the raised ground (Fig 12, E).

Areas F, G and H had been included within a previous earth resistance survey with broadly similar results to the present survey in areas F and G (Gunter and Vaughan 2005). However, far more detail has been recorded in the current survey over Area H and numerous additional anomalies have been revealed, including the pattern of discrete high resistance anomalies [r22]. It is unclear whether this differing response is due to field conditions at the time of the two surveys, or the increased sample interval of 0.5m mobile probe separation data set used for the more recent field work.

GPR

A graphical summary of the anomalies discussed in the following text, superimposed on the base Ordnance Survey map data, is provided in Figure 27. The location of the two representative GPR profiles, Lines 100 and 220 shown on Figure 19, are also illustrated on

Figure 27. Figure 19 is annotated to show the significant anomalies, although these are often more readily identified from visualisation of the data as amplitude time slices.

Background response and more recent interference

In general, the GPR response was good over the entire survey area and significant reflections were recorded to an approximate depth of 1.5m from the surface. The very near surface data between 0 and 4ns (0 to 0.15m) shows a series of linear N-S reflections from the cultivation pattern and, to a certain extent, these continue throughout the data set propagated by antenna ringing. A group of low amplitude linear anomalies [gpr1] are also evident in the later time slices beyond 20ns (0.77m) and appear to converge at the entrance gate to the field onto the A4. It seems likely that these are also related to recent agricultural activity, perhaps due to ground compaction from grain trailers during the harvest, although they appear to be obscured within the near surface data. A low amplitude anomaly [gpr2] in the NE corner of the survey area becomes visible through a similar range of time slices as [gpr1] and would appear to be related to the uncultivated bridleway adjacent to the field boundary.

The course of the pipeline, that obscured much of the magnetic data immediately S of the A4, has been resolved as two divergent linear anomalies [gpr3] visible between 8 and 34ns (0.31 to 1.31m). This response may well represent the combined reflections from the pipe trench as well as from the ferrous pipes themselves. There is some variation in the amplitude of [gpr3] across the course of the anomaly and whilst this may represent a differing depth of burial it could also be due to increased attenuation from perhaps a localised leakage of fuel oil from the pipes. The response from the pipe would also appear to be one of the deepest significant reflections recorded by the GPR, although this may again be due to antenna ringing rather than the actual physical extent of the causative feature itself.

The near-surface data also contains a pattern of more diffuse, high amplitude reflectors, which may represent a concentration of either natural gravel or ploughed out building remains within the topsoil. In this case, the spatial correlation with the location of underlying building remains is not so convincing as has been observed in GPR data from other plough damaged sites (e.g. Linford *et al.* 2008). However, this may be due to a combination of the wider down slope movement of topsoil at this site (an approximately 10m fall from W to E across the width of the GPR survey area), together with the apparently more shallow burial depth of archaeological and geomorphological features; with responses to both of these elements occurring from between 4 and 6ns (0.15 to 0.23m) suggesting a comparatively thin topsoil cover. The underlying geology, apparently a tongue of valley gravel running N-S across the A4 along the 155m contour to just beyond the Swallowhead springs (Institute of Geological Sciences 1974), is evident as a complex of high amplitude anomalies [gpr4] that may obscure the identification of more significant responses.

Significant archaeological responses

As might be expected from this technique, the GPR has not responded directly to the magnetic properties of the ditch-type anomalies but equally has not been affected by the disturbance due to the ferrous pipeline either. The locations of the three possible buildings identified in the magnetic survey [m39-41] have all been replicated within the GPR data and these appear as more complete, rectilinear anomalies [gpr5-7]. The largest and most complex of these [gpr5] is approximately 12m x 20m in extent with a number of internal room divisions. Reflections from [gpr5] are evident in the data from 10ns to 26ns (0.39 and 1.0m) where either the maximum depth of the target feature is encountered or the signal has been fully attenuated. Comparison with the magnetic survey shows a series of discrete, possibly thermoremanent anomalies within [gpr5] which may suggest further room sub-divisions partially obscured in the GPR data, perhaps by overlying rubble from the collapse of the building. There is a possible association of [gpr5] with an adjacent walled enclosure [gpr8], partially represented in the near-surface time slices between 4 and 12ns (0.15 and 0.46m) and, perhaps, a further high amplitude linear response [gpr9] following the orientation of the ditched enclosures identified by the magnetic survey.

The building at [gpr6] appears through a similar range of time slices to [gpr5] and has dimensions of 12m x 10m with a single small room division of approximately 4m square evident in the NW corner. This area is partially confused by the underlying geological response [gpr4], but some broad linear anomalies [gpr10] may, possibly, be of significance. The magnetic data corroborates the location of the walls as negative anomalies and also indicates the presence of some high amplitude positive responses within the building. Whilst it is difficult to suggest a direct correlation between these magnetic anomalies and the GPR data set it is possible that this represents the presence of internal thermoremanent sources, such as hearths or a hypocaust, within the building.

The smallest of the three buildings is found to the N at [gpr7] and is distinguished both through its reduced footprint, approximately 6m x 10m, and the more limited depth of the walls that do not appear to extend beyond 22ns (0.85m). No internal wall divisions are evident within [gpr7], although the later time slices between 16 and 20ns (0.62 and 0.77m) suggest the presence of either a solid floor within the interior of the building or a layer of collapsed rubble, perhaps from the original standing walls or the roof held within the remaining wall footings. Again, there are a number of linear anomalies [gpr11-13] that follow the orientation of the ditched enclosures revealed by the magnetic survey and may be related to [gpr7], perhaps track-ways or fragments of enclosure walls.

One further building-type anomaly [gpr14] is found in the SE corner of the GPR survey and, on initial inspection, this might be considered part of the more complex response [gpr4] associated with the valley gravel. However, from between 12 and 28ns (0.46 to 1.08m) a more convincing rectangular anomaly appears. If [gpr14] is indeed due to the presence of building remains then its dimensions, 12m x 20m, are similar to [gpr5], but it would appear to have thicker walls and, unlike the other three buildings, there is apparently no corresponding magnetic response. Other discrete high amplitude responses [gpr15-18] are scattered throughout the survey area, although these may not, necessarily, be related to structural remains. The anomaly at [gpr18] is in the vicinity of one of the Roman wells recorded on the historic mapping (OS Historic County Mapping Series: Wiltshire, 1887) and may be related to this, or a similar feature associated with antiquarian investigations over the site.

GPR and ERT transects across the Silbury ditch

Graphical depictions of the ERT and GPR transects over the ditch around the base of Silbury Hill are shown in Figures 22 and 23.

Examination of the ERT transects suggests that in all cases the topmost part of the ditch fill consists of a very conductive layer of material with an electrical resistivity in the range between 4 and 10 Ωm (depicted in blue in the ERT plots in Figures 22 and 23) extending to approximately 2m beneath the surface. Beneath this is a less conductive layer exhibiting electrical resistivities between 10 and 65 Ωm (depicted with a gradation of colours from green through yellow to brown) and with a thickness of 1.5 to 2m. Where the ERT transects extend well beyond the edge of the ditch, such as at the right hand ends of Radials 3 and 5 (Figure 22 (C) and (E)), the underlying chalk (or gravel) begins closer to the surface and demonstrates a value for its electrical resistivity between 75 and 120 Ωm.

On each plot the depth at which resistivity values first attain a value greater than 75 Ωm has been indicated as a black dashed line as this threshold is likely to represent the boundary between the ditch fill and the underlying natural geology. It has not been possible to trace this interface across the central portion of any of the radial transects, because in these positions the threshold resistivity value is not attained within the maximum recorded depth range of approximately 4m.

In general, the low centre frequency (110MHz) GPR transects agree well with the ERT results and identify a relatively homogeneous upper ditch layer defined by a basal reflector at about 2m from the surface (indicated by a red dashed line on the GPR profiles shown on Figures 22 and 23). It is possible that this interface represents the boundary between the ditch cut and the underlying natural interpreted from the change in resistivity recorded by the ERT data. Reflections from beneath this interface are more difficult to interpret and it would appear that a combination of antenna ringing and the rapid attenuation of the signal limit much further resolution of detail to a greater depth. Results from the 225MHz centre frequency antenna are more variable, although appear to resolve the near surface, high resistance anomalies due to the underlying geology well (e.g. Radials 1, 5 and 9 shown in Figure 22 (A), (E) and Figure 23 (I)) and in part the apparent interface layer too (e.g. Radials 6, 7, 9 and 11 together with Extensions 1 and 2 shown in Figure 22 (F) and Figure 23 (G), (I), (J), (K) and (L)).

The ERT and GPR measurements may be interpreted as indicating that the upper 2m of the Silbury Hill ditch fill consists of a relatively homogenous layer of alluvial silts. Beneath this there is some evidence to suggest a second layer, between 1.5 and 2m thick, consisting of a higher resistivity mix of alluvium and weathered chalk rubble. In those parts of the ditch furthest from the hill, including in the western ditch extension, the geophysical results appear to indicate an interface with the natural chalk at a depth of between 3.5 and 4m. However, close to the hill itself the measurements are more equivocal and it is not clear that the interface has been detected, suggesting that it might lie deeper than the ~4m depth that the two techniques employed were able to image reliably.

This geophysical evidence can be compared with the excavation evidence recorded by Pass (1887) who dug ten exploratory pits into the ditch on the western and northern sides of the hill. Pass's findings are summarised in the context of the other evidence for the nature of the Silbury Hill ditch collected during Atkinson's 1968 excavations in Field (2002), from which the details discussed here are taken. The evidence from Atkinson's excavation itself may be less relevant as it focuses on the southern portion of the ditch, where it appears to be much deeper and narrower than elsewhere around the hill as it is constricted to run through the gap between the hill and the raised causeway constructed to carry the modern A4.

Pass found that within the ditches the natural chalk had been dug out to a depth of 4.6m below the current ground surface in most places but, close to the hill base, he found this depth increased to 6.4m. The shallower depth accords reasonably well with the total depth of the two layers detected by the ERT and GPR techniques, which varies between 3.5 and 4m, although it does suggest that both methods are underestimating depths to the interfaces to some extent; neither technique was able to resolve details deeper than about 4m owing to site conditions. A limitation of the ERT method is that when the upper subsurface is very conductive, as the upper alluvial layer is in the Silbury ditch, the electric current flows through this layer preferentially and very little penetrates deeper into the subsurface meaning that any potential differences caused by deeper lying features are too small to be detected. The GPR signal will also be heavily attenuated by conductive media, resulting in reduced depth penetration.

One further piece of evidence noted by Pass in the trench he excavated nearest to the western ditch terminal was the discovery of a Roman coin of *Marcus Aurelius* at a depth of 1.8m. This suggests that the 2m thick conductive upper layer detected by the ERT and GPR may represent alluvial deposition since the Roman period with the second, more heterogeneous, layer beneath representing accumulation before this date. Field also notes a linear vegetation mark running diagonally across the western ditch extension and visible briefly during fieldwork in early summer 2001 (Field 2002, p61). However, the geophysical transects across the ditch extension offer no further clues as to its cause.

DISCUSSION

Perhaps the most significant revelation from the campaign of geophysical field work at Silbury has been the discovery of a sizeable, presumably Roman, settlement to the S of the A4. Whilst Roman activity has long been recognised in the vicinity of Silbury Hill and considerable evidence found to support speculation that such a settlement should indeed exist (e.g. Brooke and Cunnington 1896; Brooke 1910; Powell *et al.* 1996; Corney 1997, 2001; Robinson 2001), the geophysical survey convincingly unveils the extent of this occupation over an area of otherwise limited archaeological visibility. In particular, the geophysical survey results further indicate the presence of substantial masonry buildings, perhaps first recognised by Revd. Wilkinson (Wilkinson 1869) and seen later as tantalising glimpses along the course of the foul sewer pipe trench to the N of the A4 (Powell *et al.*

1996, Building I and Building II). However, the geophysical data provides details of buildings in the newly discovered settlement to the S and, to the N, in the immediate vicinity of the Roman buildings found along the pipe trench, a possible water mill – suggested by its apparent association with culverts in the immediate vicinity.

The detail revealed by the GPR data demonstrates both the complexity of the masonry buildings, including internal room divisions, and evidence for surviving floors and associated thermoremanent magnetic anomalies that may well indicate the presence of a hypocaust heating system. Despite the possible threat from plough damage, the level of preservation appears to be relatively good with significant wall remains extending to at least 1m in depth from the current ground surface. It is possible that colluvial deposits washed downhill have contributed to the preservation of the building remains, whilst also obscuring their identification through crop marks.

Powell *et al.* (1996) described the extensive Roman activity revealed by the foul sewer excavations as the "Winterbourne Romano-British settlement". However, the much larger scale of this occupation, evident from cropmarks on the western slope of Waden Hill and the new geophysical survey data suggests that acknowledging Silbury Hill itself as the focus of the Roman activity is perhaps more correct (e.g. Corney 1997). The importance of the water course is still entirely valid, although it is now clear that the Roman settlement extends some distance to the S of the modern A4 encompassing the Swallowhead springs. The practical need to cross the river at some point over the low lying terrain immediately E of Silbury Hill could, to some extent, explain the development of a Roman settlement in the vicinity. Such a river crossing would be necessary not only for the major E-W Roman road from *Cunetio* to *Aquae Sulis*, but also to join the extensive settlement now recognised to the N and S. The importance of a minor N-S route has, perhaps, been overlooked; although Corney (1997) postulated from the AP evidence that this may well have run along the Winterbourne valley N to Avebury and the geophysical data now suggests a possible continuation to the S. Such a confluence of roadways at a defined river crossing certainly enhances the possibility that the Roman settlement at Silbury, in addition to any other agricultural role, may also have supported some function as a *mutatio* or *mansio* (e.g. Farley 1971 ; Burnham and Wacher 1990).

At Silbury one can never escape the significance of the ritual landscape, centred upon the manifestation of the hill and surrounding ditch. This together with the river and the Swallowhead springs must to some extent have influenced the development of Roman occupation at the site, perhaps even segregating the use of space within the settlement. Immediately E of the hill there would certainly appear to be a contrast from the rectilinear, ladder-style pattern of settlement found to the N in the crop marks and to the S in the geophysical data. However, in the absence of any more direct evidence, barring the presence of one of the Roman wells in this area, the function and indeed date of the enclosure activity adjacent to the hill remains uncertain; very speculatively, though, it is tempting to suggest that anomalies such ([m17] and [m18]) might reflect a continuing element of sanctity in this area. It is also, of course, possible that this lower lying area was an active seasonal flood plain during the Roman period and the concentration of settlement would therefore be expected to be found on the higher ground.

CONCLUSION

The results of the wider area geophysical survey at Silbury hill successfully expand upon the initial investigation in the immediate vicinity of the monument (Payne *et al.* 2006). Continued use of the high sensitivity caesium magnetometer array has been justified through the identification of anomalies over lower-lying ground, where both hill wash and alluvial deposits obscure the ready identification of archaeological activity. The magnetic survey has, in particular, revealed a continuation of the apparently Roman settlement to the S of the A4 extending considerably beyond the previously identified activity of the same period clustered along the course of the Roman road. The size, function and importance of the Roman settlement at Silbury must now be revised in light of the these geophysical findings. Taken together with the known evidence, including the crop marks and observations along the foul sewer trench to the E on the flanks of Waden hill, the geophysical evidence suggests the Roman settlement extends over 400m to both the N and to the S of a focus centred on Silbury Hill itself. The continuation of settlement traces extending both to the N and SW beyond the current survey coverage would also seem likely.

Other, more enigmatic, anomalies have been found across the lower-lying water meadow, particularly in association with an area of raised ground to the S of the A4. Both the geophysical response and the topographic relief suggest a deliberate construction, yet the form is unusual and defies immediate interpretation without invasive work.

The range of geophysical techniques applied at Silbury has also been expanded to include the use of both earth resistance tomography (ERT) and ground penetrating radar (GPR). A large scale GPR survey was successfully conducted over the likely location of masonry structures identified from the magnetic data to the S of the hill. These results confirmed the presence of at least three large Roman buildings, suggested the possibility of a fourth, and provided additional details of internal room divisions, possible intact floor layers and the depth extent of the surviving causative features. GPR was also combined with a number of ERT profiles set out across the Silbury Hill ditch and quarry extension to the W. However, neither technique appears to have imaged the ditch to the depth envisaged from Pass's or Atkinson's excavation data, perhaps due to the relatively near-surface highly conductive alluvial deposits present at the top of the feature.

LIST OF ENCLOSED FIGURES

mobile probe separations have also been combined into (G) a linear greyscale image of the overlaid data sets (1:1000).

Figure 12 Earth resistance data collected with a 0.5m mobile probe spacing from Area H shown as (A) a traceplot and (B) an equal area greyscale image of the minimally processed raw data. Similar plots of the 1.0m mobile probe spacing measurements are shown in parts (C) and (D). The two mobile probe separations have also been combined into (E) a linear greyscale image of the overlaid data sets (1:1000).

Figure 13 Earth resistance data collected with a 0.5m mobile probe spacing from Area E shown as (A) a traceplot and (B) an equal area greyscale image of the minimally processed raw data, together with (C) a linear greyscale image of the filtered data. Parts (D), (E) and F) show similar plots of the 1.0m mobile probe spacing measurements (1:1000).

Figure 14 Earth resistance data collected with a 0.5m mobile probe spacing from Area G shown as (A) a traceplot and (B) an equal area greyscale image of the minimally processed raw data, together with (C) a linear greyscale image of the filtered data. Parts (D), (E) and F) show similar plots of the 1.0m mobile probe spacing measurements (1:1000).

Figure 15 Greyscale image of the combined square array earth resistance data superimposed over the base OS mapping (1:2500).

Figure 16 Minimally processed equal area greyscale images of (A) alpha and (B) beta configurations of the square array earth resistance data from Area A, together with (C) a traceplot and (D) an equal area greyscale image of the combined data sets (1:1000).

Figure 17 Minimally processed equal area greyscale images of (A) alpha and (B) beta configurations of the square array earth resistance data from Area Dii, together with (C) a traceplot and (D) an equal area greyscale image of the combined data sets. A linear greyscale image (E) of the filtered combined data is also shown (1:2000).

Figure 18 Greyscale image of the GPR amplitude time slice from 18 to 20ns (0.69 to 0.77m) superimposed over the base OS mapping (1:2500).

Figure 19 Representative profiles from the GPR survey shown as greyscale images with annotation denoting significant anomalies. The location of the selected lines can be found on Figure 27.

Figure 20 Greyscale images GPR amplitude time slices from 0 to 20ns (0 to 0.77m), where each successive time slice is integrated over a non-overlapping time window of 2ns (1:2500).

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ANNEX 1: NOTES ON STANDARD PROCEDURES

1) Earth Resistance Survey

Each 30 metre grid square is surveyed by making repeated parallel traverses across it, all aligned parallel to one pair of the grid square's edges, and each separated by a distance of 1 metre from the last; the first and last traverses being 0.5 metres from the nearest parallel grid square edge. Readings are taken along each traverse at 1 metre intervals, the first and last readings being 0.5 metres from the nearest grid square edge.
Unless otherwise stated the measurements are made with a Geoscan RM15 earth resistance meter incorporating a built-in data logger, using the twin electrode configuration with a 0.5 metre mobile electrode separation. As it is usually only relative changes in earth resistance that are of interest in archaeological prospecting, no attempt is made to correct these measurements for the geometry of the twin electrode array to produce an estimate of the true apparent resistivity. Thus, the readings presented in plots will be the actual values of earth resistance recorded by the meter, measured in Ohms (Ω). Where correction to apparent resistivity has been made, for comparison with other electrical prospecting techniques, the results are quoted in the units of apparent resistivity, Ohm-m (Ωm).

Measurements are recorded digitally by the RM15 meter and subsequently transferred to a portable laptop computer for permanent storage and preliminary processing. Additional processing is performed on return to Fort Cumberland using desktop workstations.

2) Magnetometer Survey

Each 30 metre grid square is surveyed by making repeated parallel traverses across it, all parallel to that pair of grid square edges most closely aligned with the direction of magnetic N. Each traverse is separated by a distance of 1 metre from the last; the first and last traverses being 0.5 metre from the nearest parallel grid square edge. Readings are taken along each traverse at 0.25 metre intervals, the first and last readings being 0.125 metre from the nearest grid square edge.

These traverses are walked in so called 'zig-zag' fashion, in which the direction of travel alternates between adjacent traverses to maximise survey speed. Where possible, the magnetometer is always kept facing in the same direction, regardless of the direction of travel, to minimise heading error. However, this may be dependent on the instrument design in use.

Unless otherwise stated the measurements are made with either a Bartington Grad601 or a Geoscan FM36 fluxgate gradiometer which incorporate two vertically aligned fluxgates, one situated either 1.0m or 0.5 metres above the other; the bottom fluxgate is carried at a height of approximately 0.2 metres above the ground surface. Both instruments incorporate a built-in data logger that records measurements digitally; these are subsequently transferred to a portable laptop computer for permanent storage and preliminary processing. Additional processing is performed on return to Fort Cumberland using desktop workstations.

It is the opinion of the manufacturer of the Geoscan instrument that two sensors placed 0.5 metres apart cannot produce a true estimate of vertical magnetic gradient unless the bottom sensor is far removed from the ground surface. Hence, when results are presented, the difference between the field intensity measured by the top and bottom sensors is quoted in units of nano-Tesla (nT) rather than in the units of magnetic gradient, nano-Tesla per metre (nT/m).

3) Resistivity Profiling

This technique measures the electrical resistivity of the subsurface in a similar manner to the standard resistivity mapping method outlined in note 1. However, instead of mapping changes in the near surface resistivity over an area, it produces a vertical section, illustrating how resistivity varies with increasing depth. This is possible because the resistivity meter becomes sensitive to more deeply buried anomalies as the separation between the measurement electrodes is increased. Hence, instead of using a single, fixed electrode separation as in resistivity mapping, readings are repeated over the same point with increasing separations to investigate the resistivity at greater depths. It should be noted that the relationship between electrode separation and depth sensitivity is complex so the vertical scale quoted for the section is only approximate. Furthermore, as depth of investigation increases the size of the smallest anomaly that can be resolved also increases.

Typically a line of 25 electrodes is laid out separated by 1 or 0.5 metre intervals. The resistivity of a vertical section is measured by selecting successive four electrode subsets at increasing separations and making a resistivity measurement with each. Several different schemes may be employed to determine which electrode subsets to use, of which the Wenner and Dipole-Dipole are typical examples. A Campus Geopulse earth resistance meter, with built in multiplexer, is used to make the measurements and the Campus Imager software is used to automate reading collection and construct a resistivity section from the results.

Figure 1

SILBURY HILL, WILTSHIRE

Location of geophysical surveys, February 2005 - February 2008

0 120m

1:4000

- Caesium magnetometer survey
- Fluxgate magnetometer survey
- Square array resistance survey
- Twin probe resistance survey
- GPR area survey
- GPR and ERT transects
- *S of the A4* Magnetic survey areas referred to in text
- *A-G* Resistance survey areas referred to in text

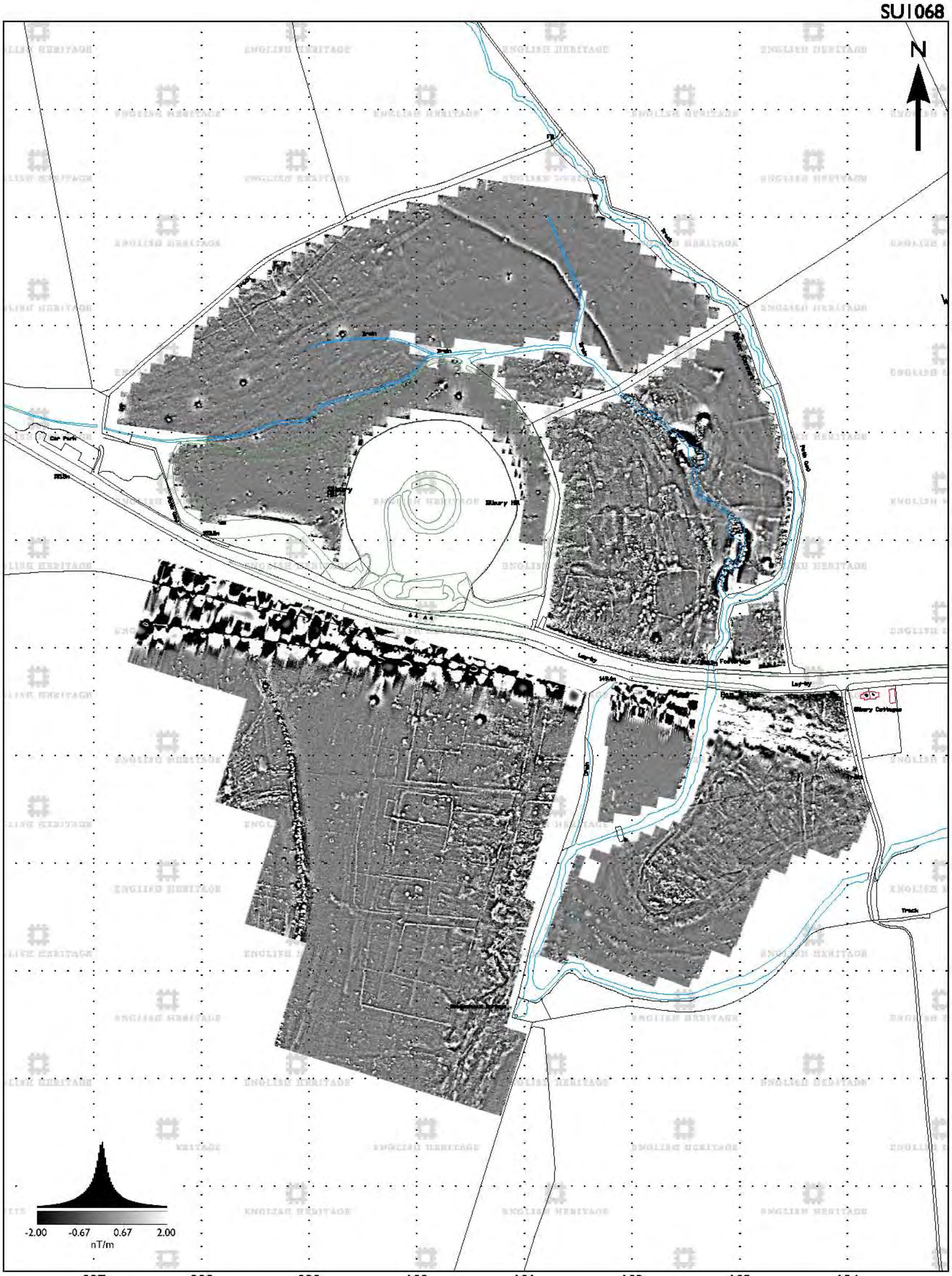
Geophysics Team 2009

ENGLISH HERITAGE

SILBURY HILL, WILTSHIRE

Location of magnetic surveys, February 2005 - February 2008

Figure 2

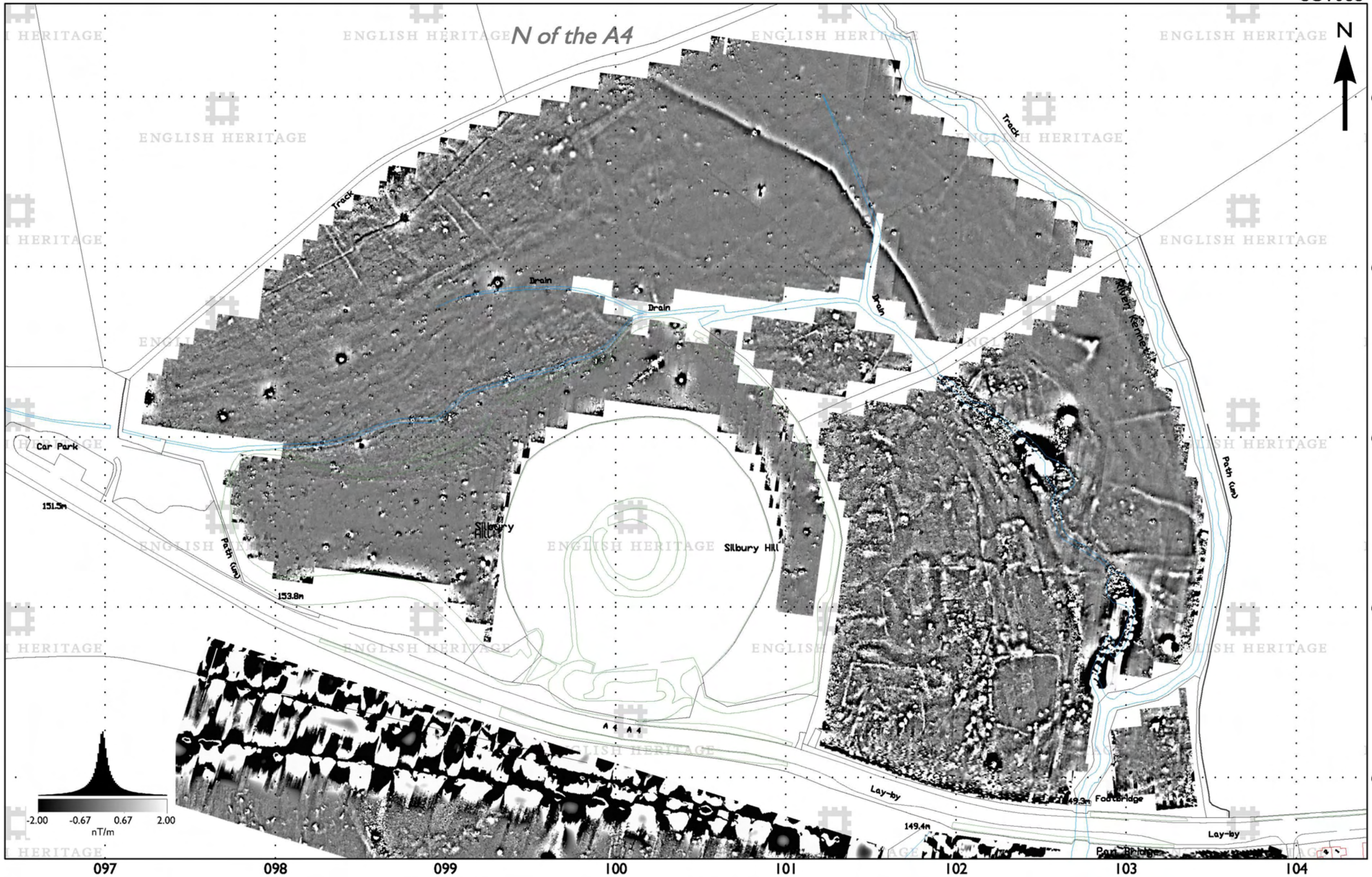


0 120m

1:4000

SILBURY HILL, WILTSHIRE
Location of magnetic surveys N of the A4, February 2005 - March 2006

Figure 3



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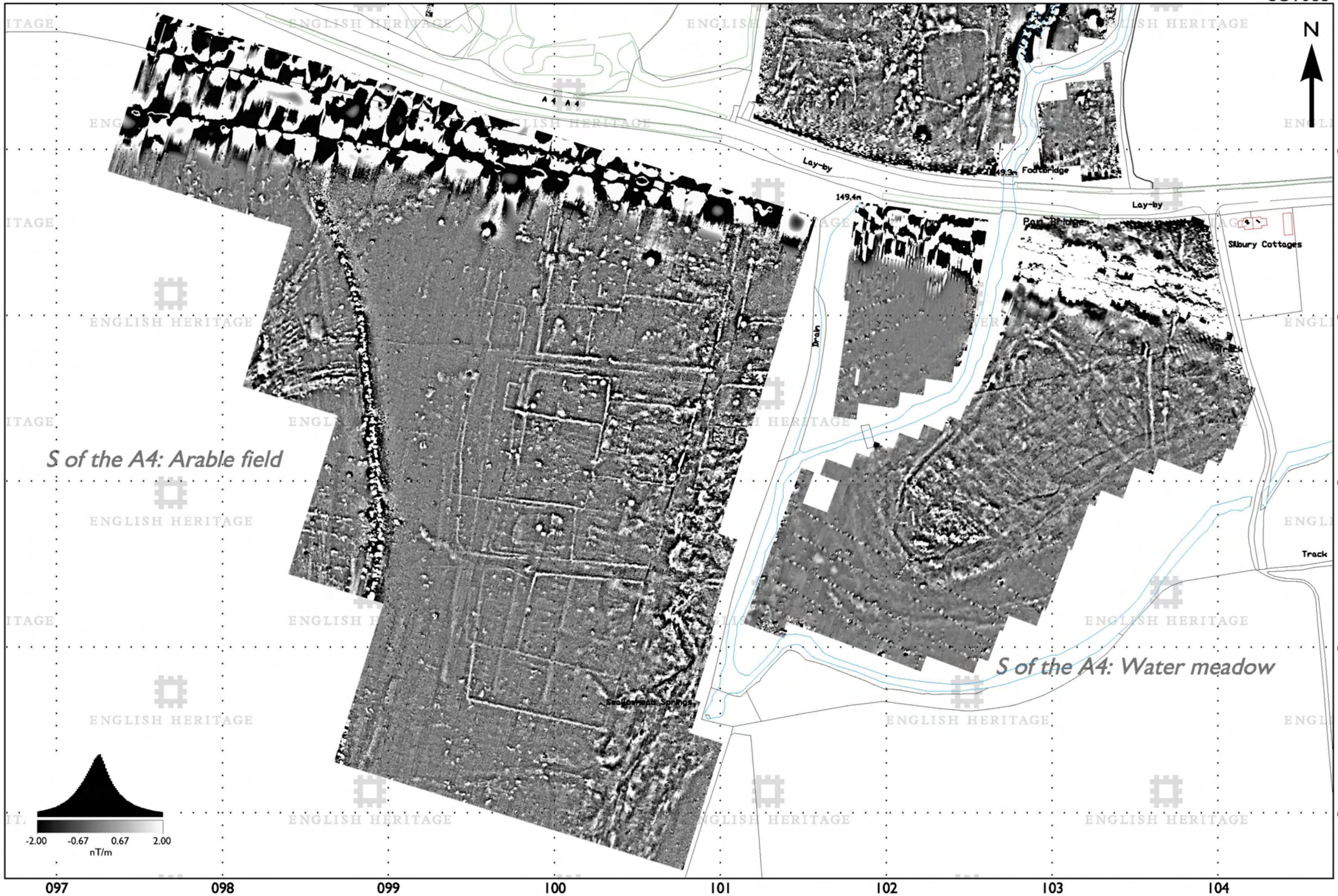
Location of magnetic surveys S of the A4, October 2006 - February 2008

Figure 4



0 90m

1:2500

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Magnetic surveys N of the A4, February 2005, March 2006 and February 2008

Figure 5

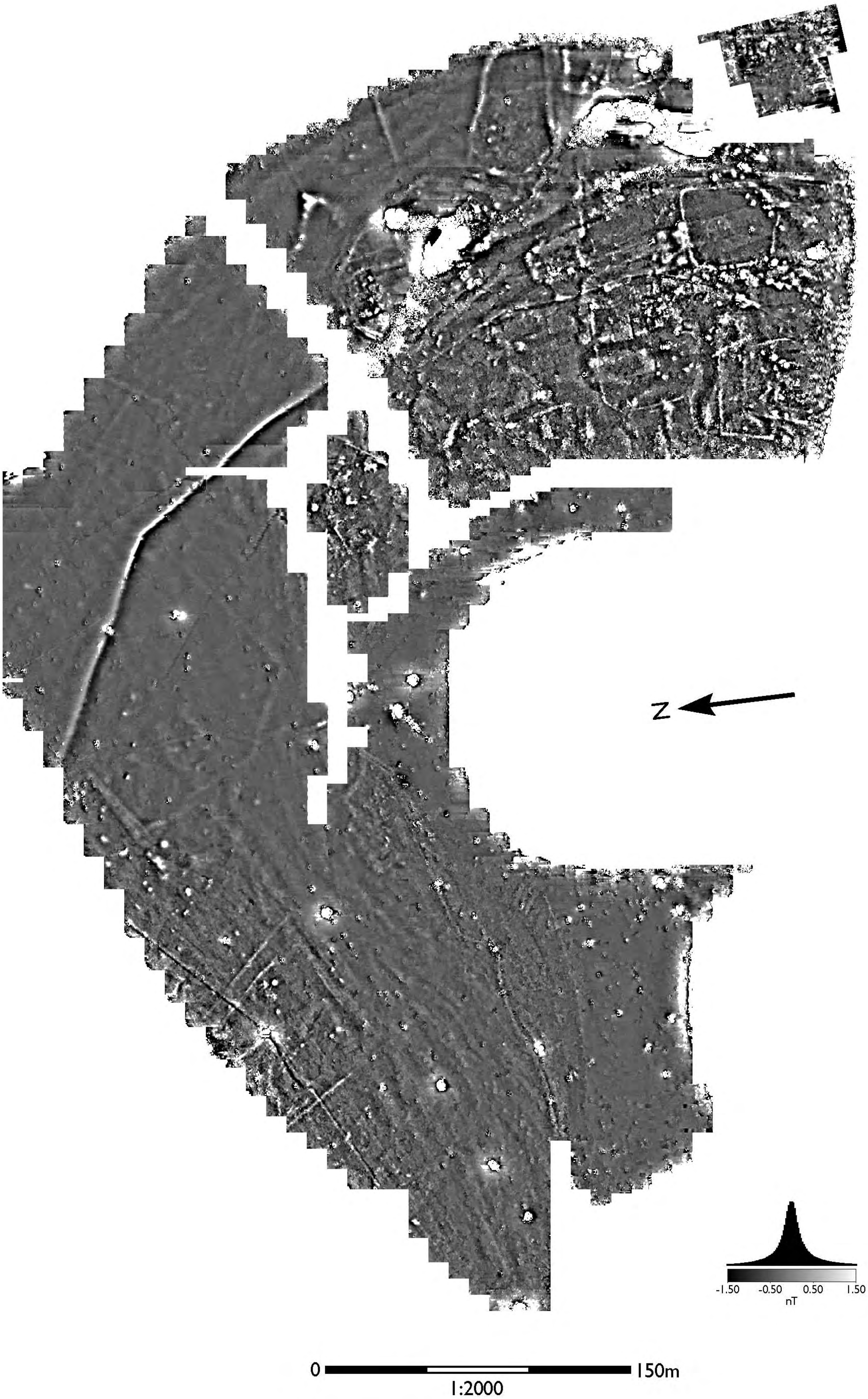

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Figure 6

Magnetic surveys N of the A4, February 2005, March 2006 and February 2008

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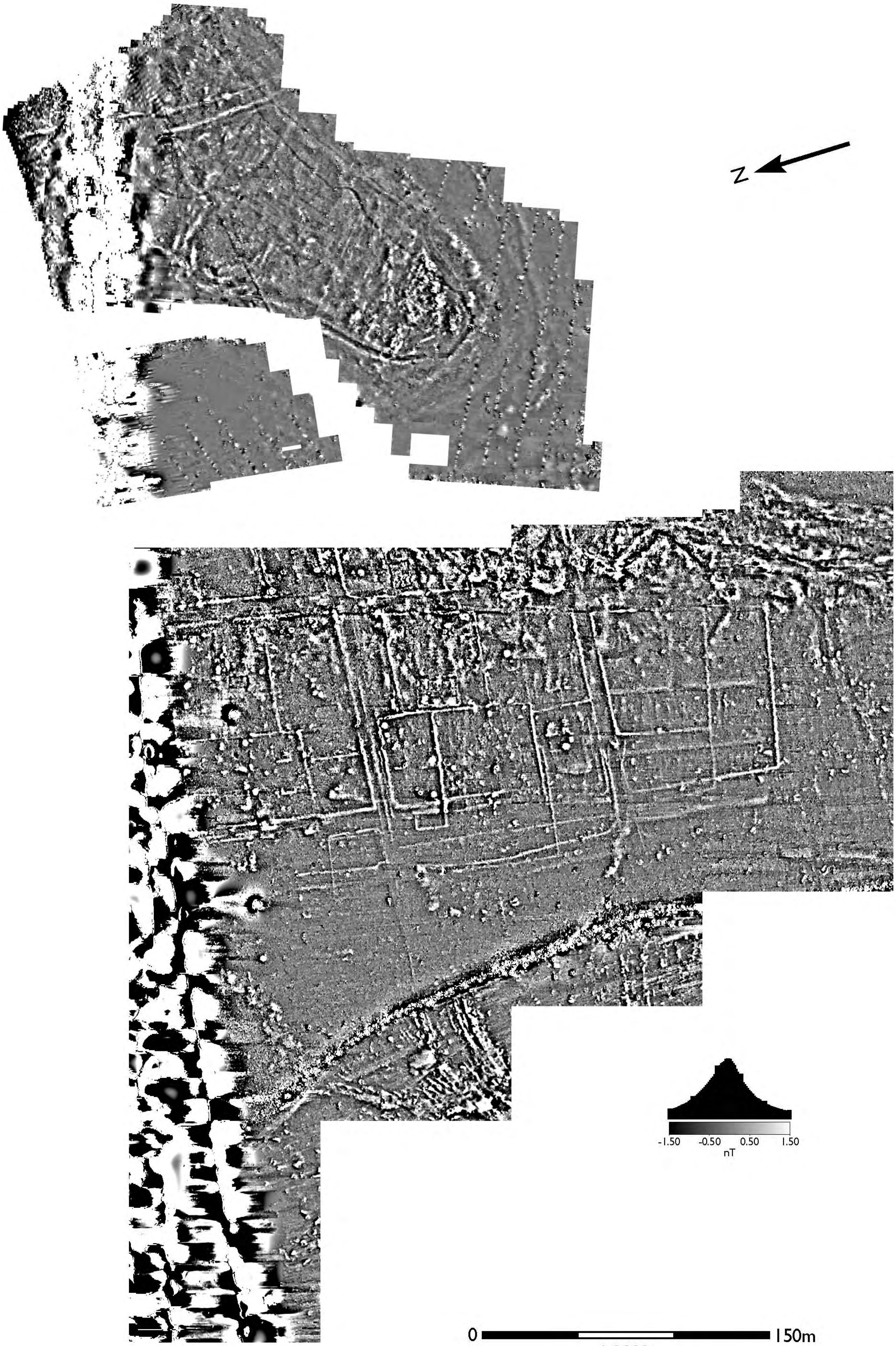
Magnetic surveys S of A4, October 2006, July 2007 and February 2008

Figure 7



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Magnetic surveys S of the A4, October 2006, July 2007 and February 2008

Figure 8

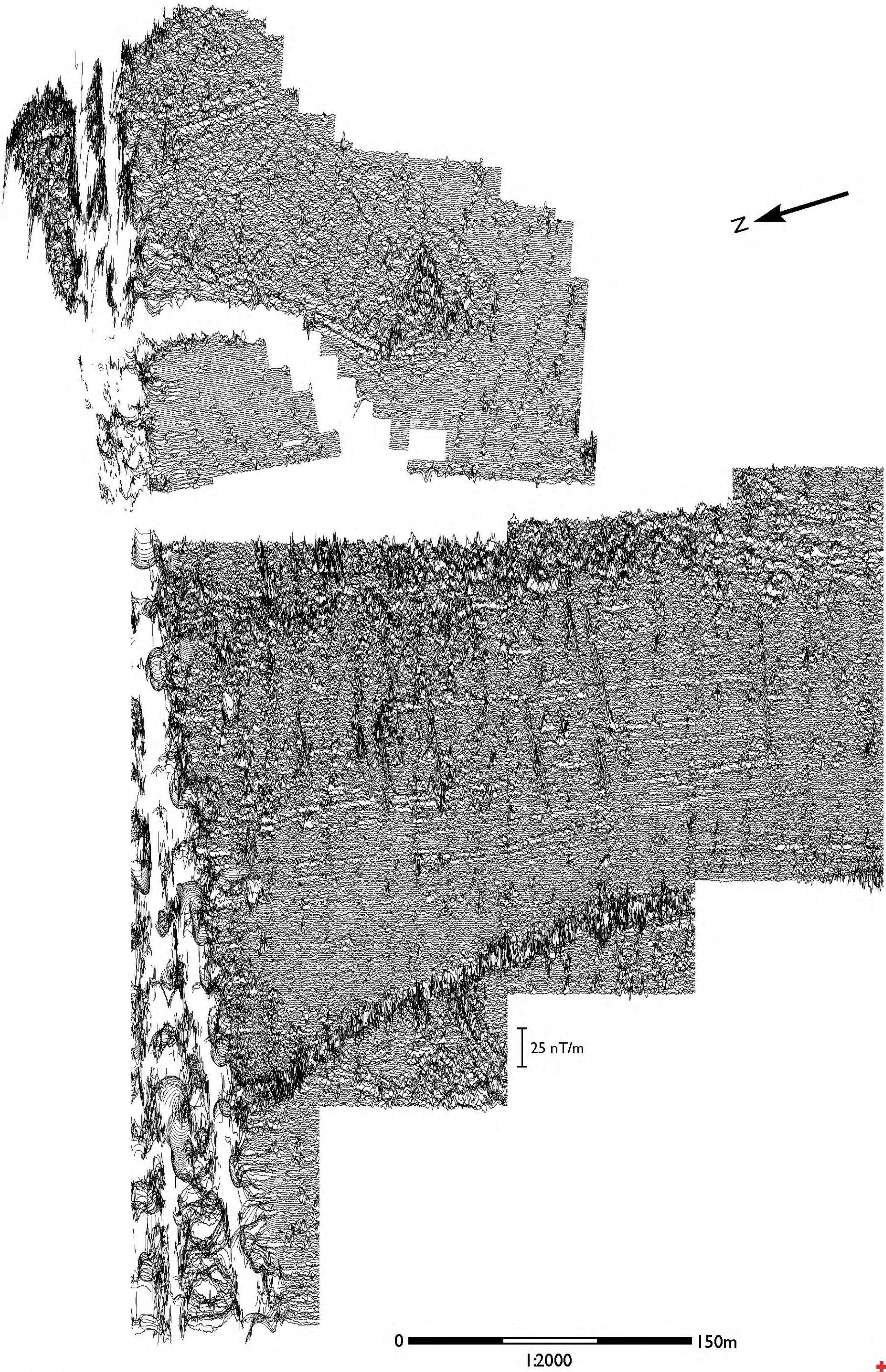

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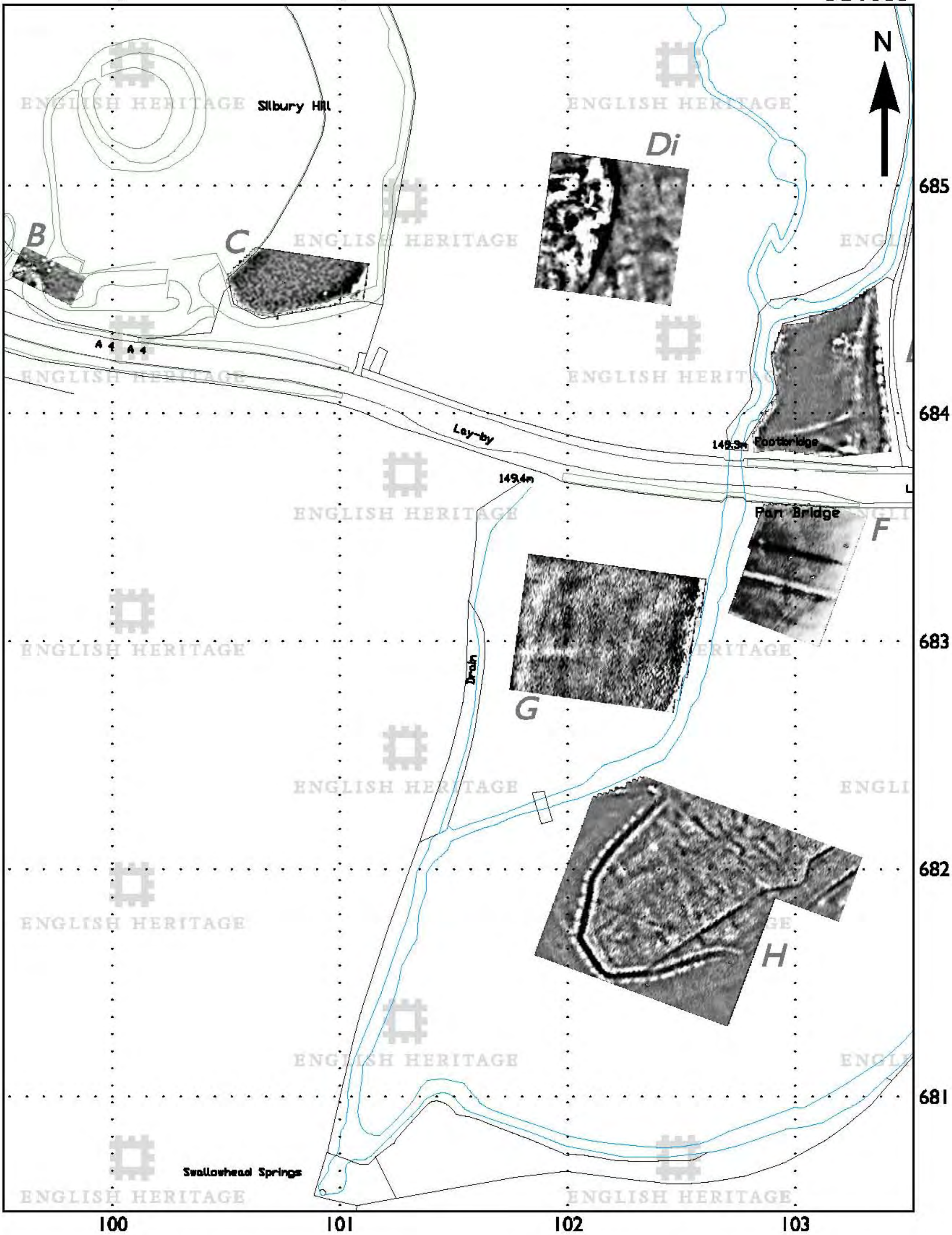
Figure 9

Location of twin electrode earth resistance surveys, February 2005 - February 2008

SU1068



Low High

Ω

0 90m

1:2500

See Figures 11-14 for more detail

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Twin probe earth resistance surveys of Areas B, C and Di, February 2005 - May 2006

Figure 10

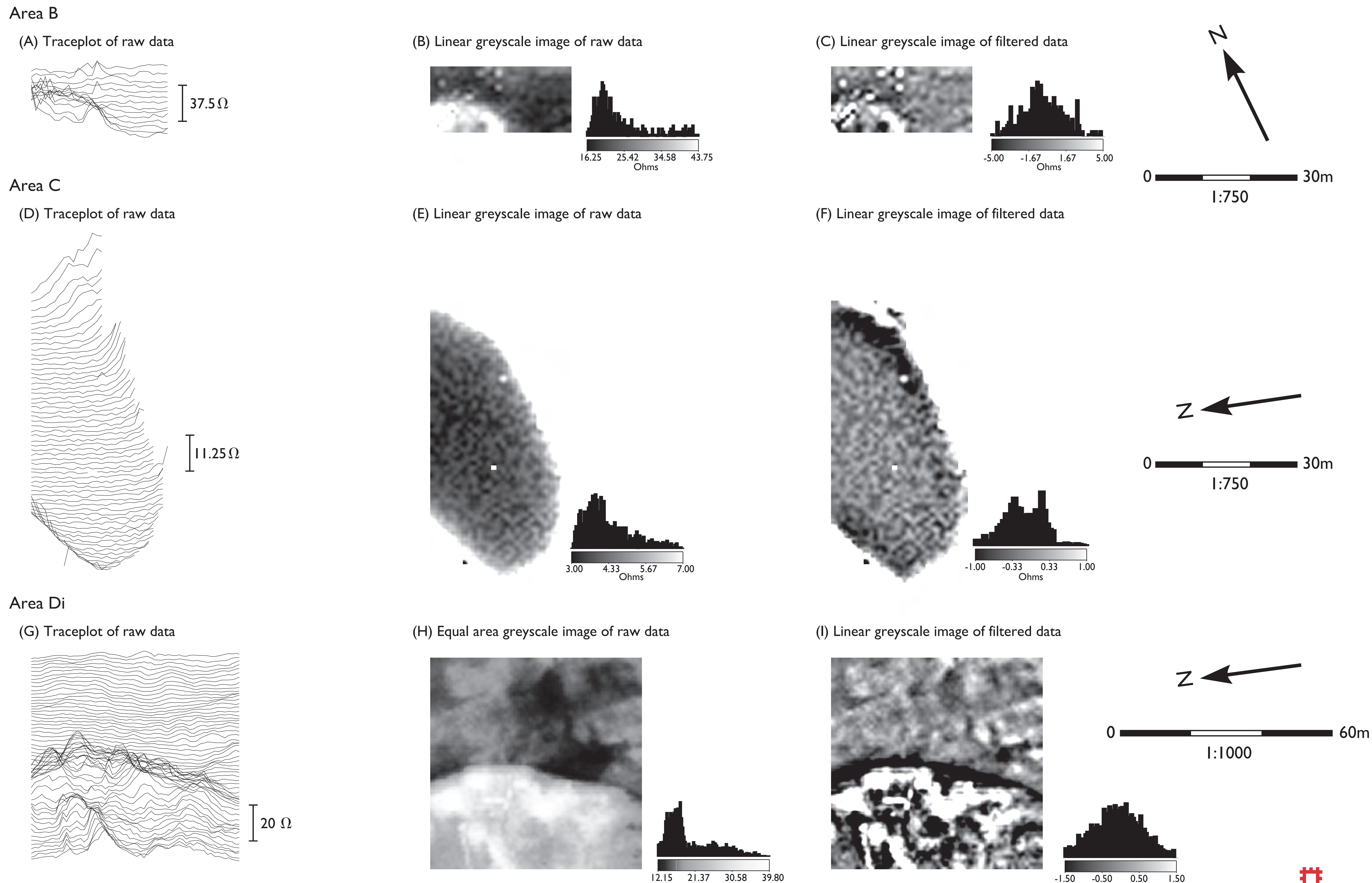

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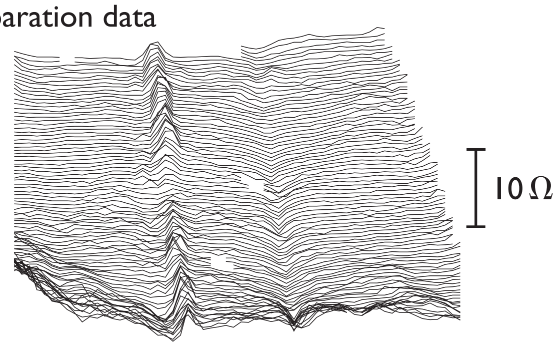
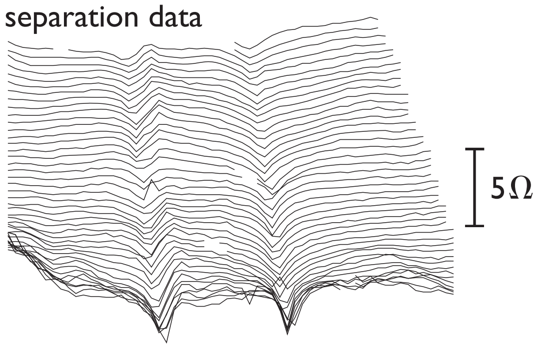
Figure 11

Twin probe earth resistance surveys of Area F, July 2007

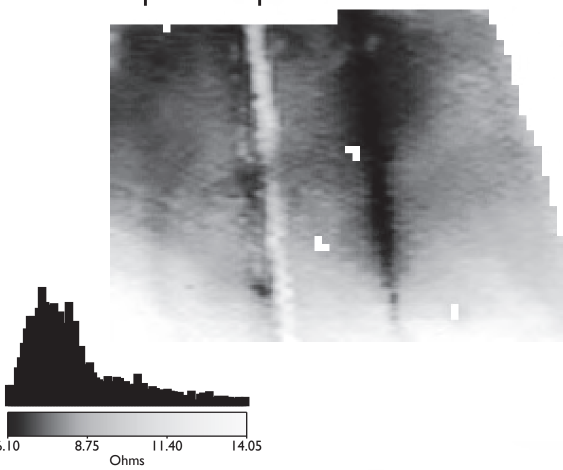
(A) Traceplot of raw 0.5m mobile probe separation data



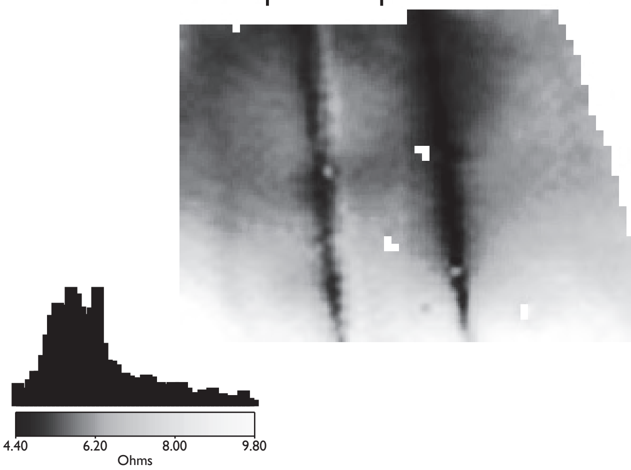
(D) Traceplot of raw 1.0m mobile probe separation data



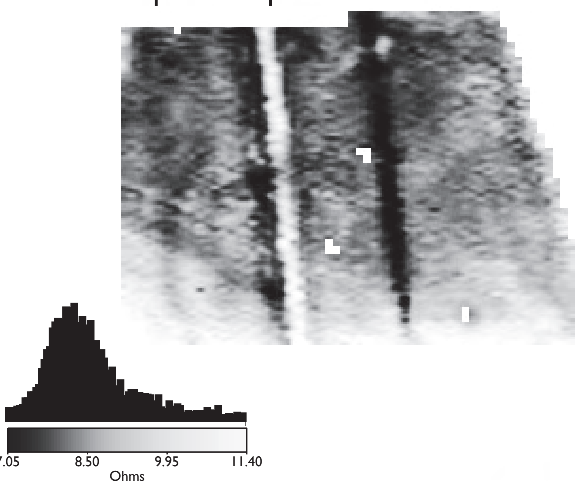
(B) Equal area greyscale image of raw 0.5m mobile probe separation data



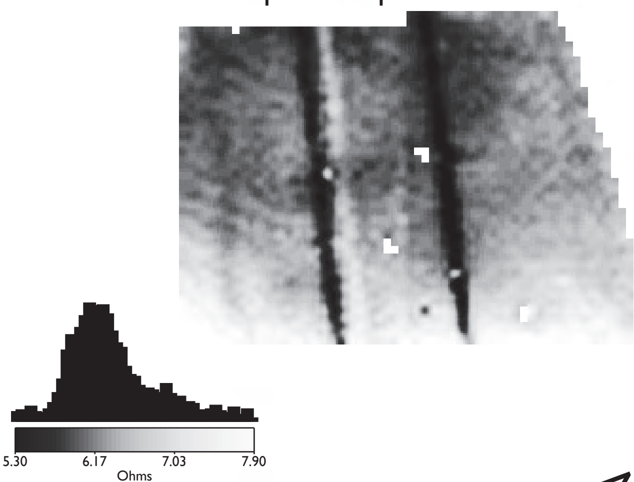
(E) Equal area greyscale image of raw 1.0m mobile probe separation data



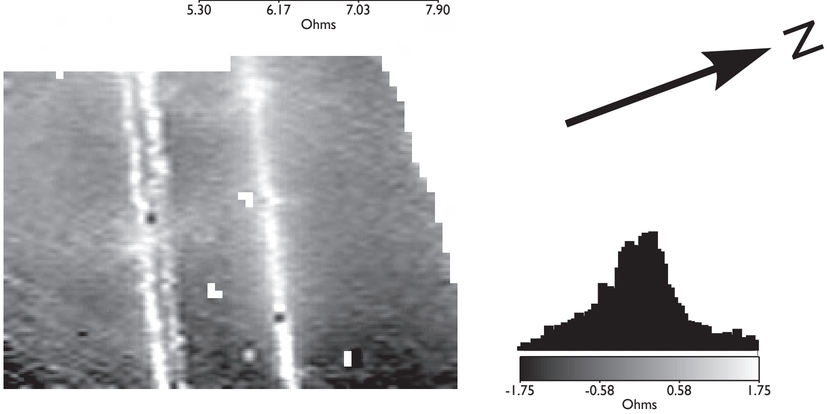
(C) Equal area greyscale image of filtered 0.5m mobile probe separation data



(F) Equal area greyscale image of filtered 1.0m mobile probe separation data



(G) Linear greyscale image of overlaid data



0 60m

1:1000

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Twin probe earth resistance surveys of Area H, July 2007

Figure 12

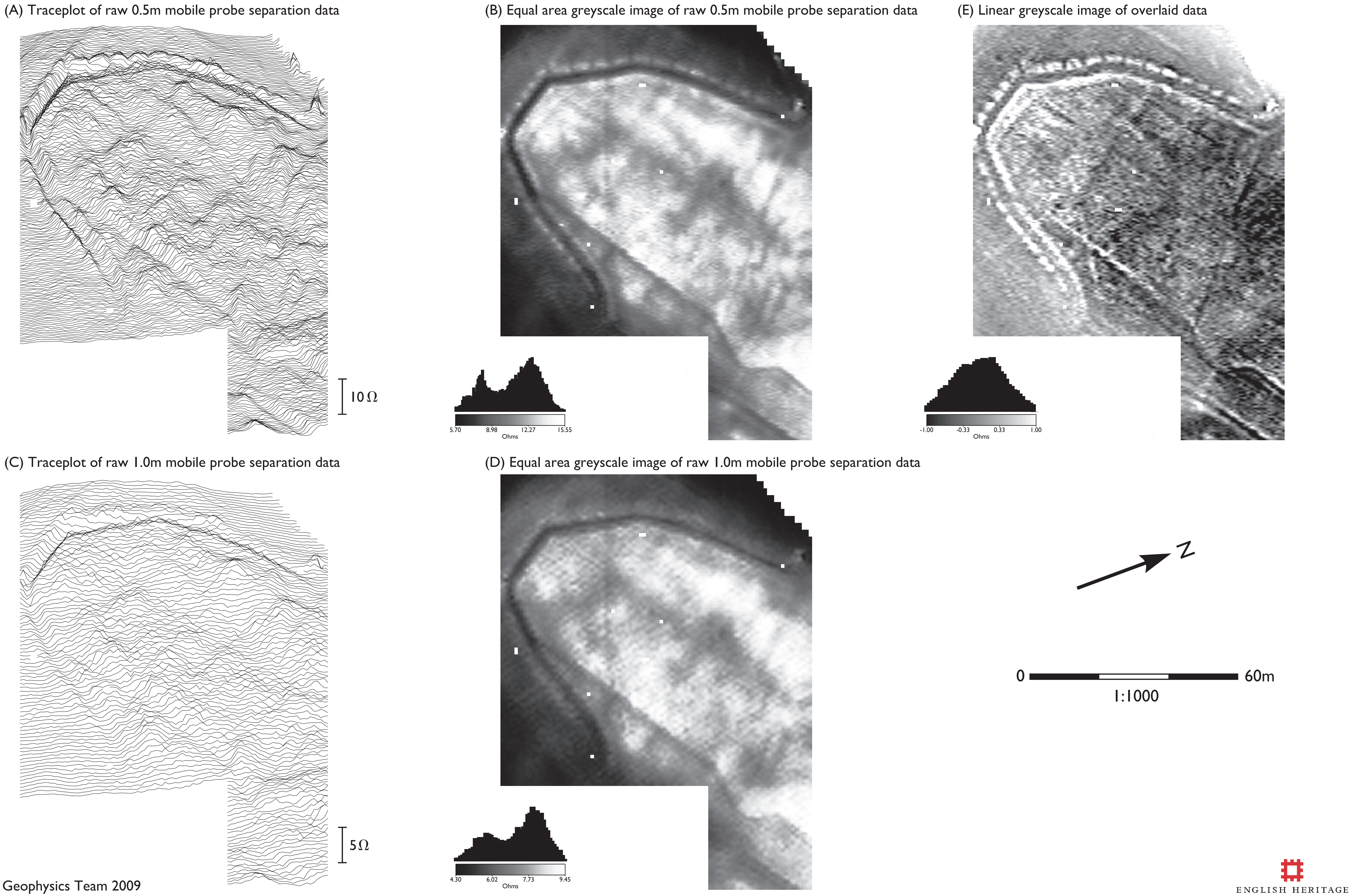

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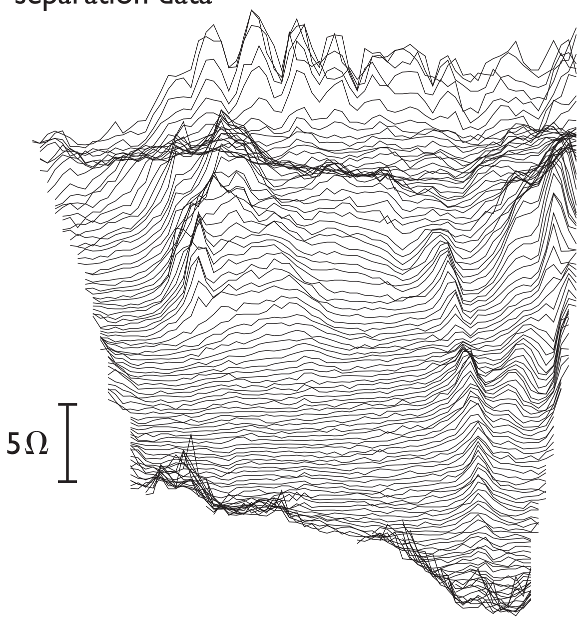
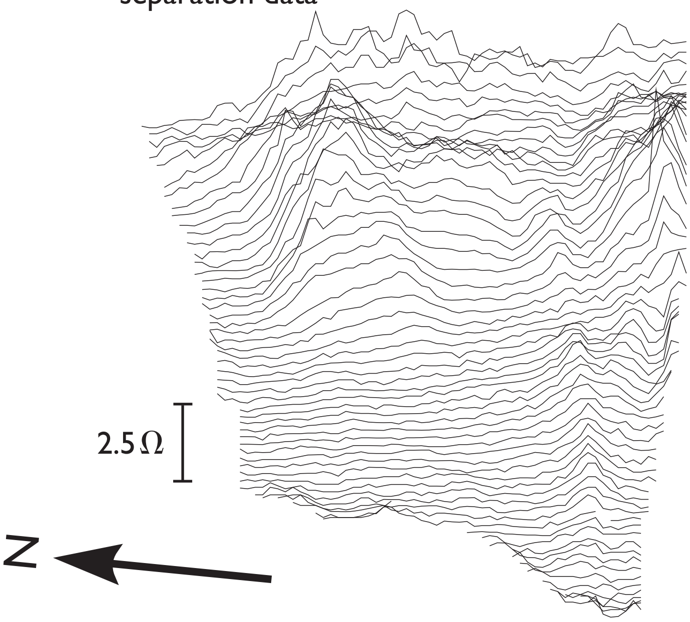
Figure 13

Twin probe earth resistance surveys of Area E, February 2008

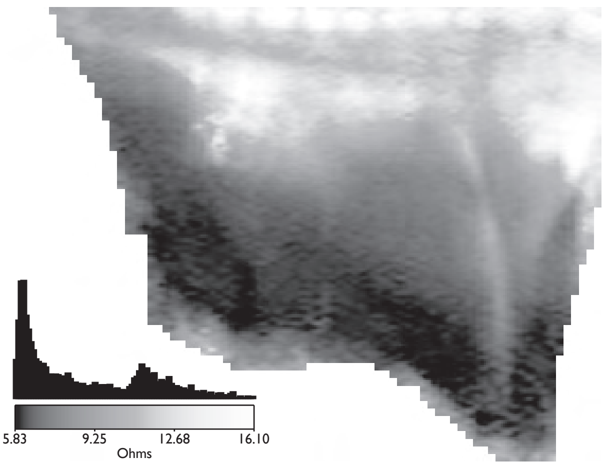
(A) Traceplot of raw 0.5m mobile probe separation data



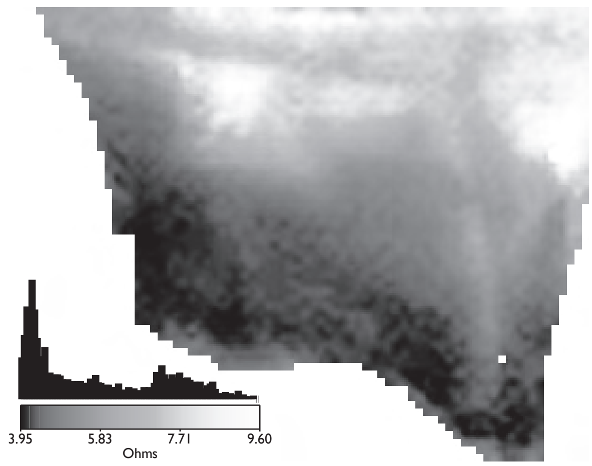
(D) Traceplot of raw 1.0m mobile probe separation data



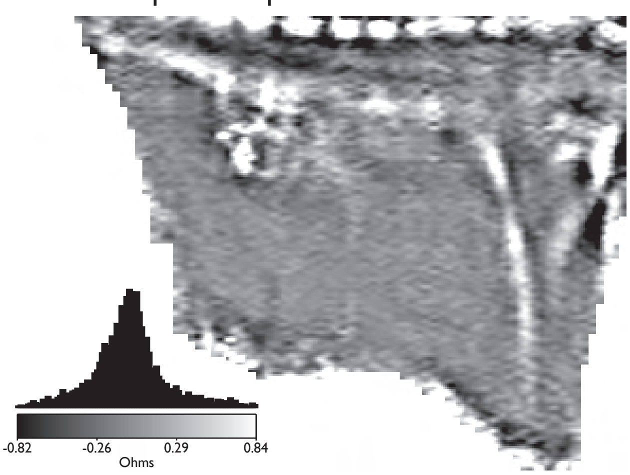
(B) Equal area greyscale image of raw 0.5m mobile probe separation data



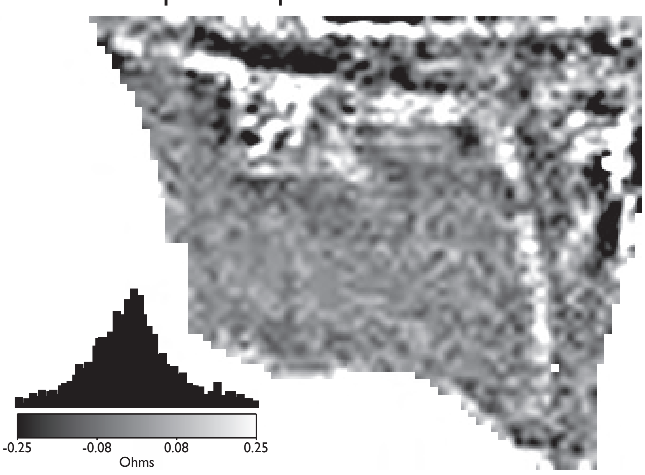
(E) Equal area greyscale image of raw 1.0m mobile probe separation data



(C) Linear greyscale image of filtered 0.5m mobile probe separation data



(F) Linear greyscale image of filtered 1.0m mobile probe separation data



0 60m

1:1000

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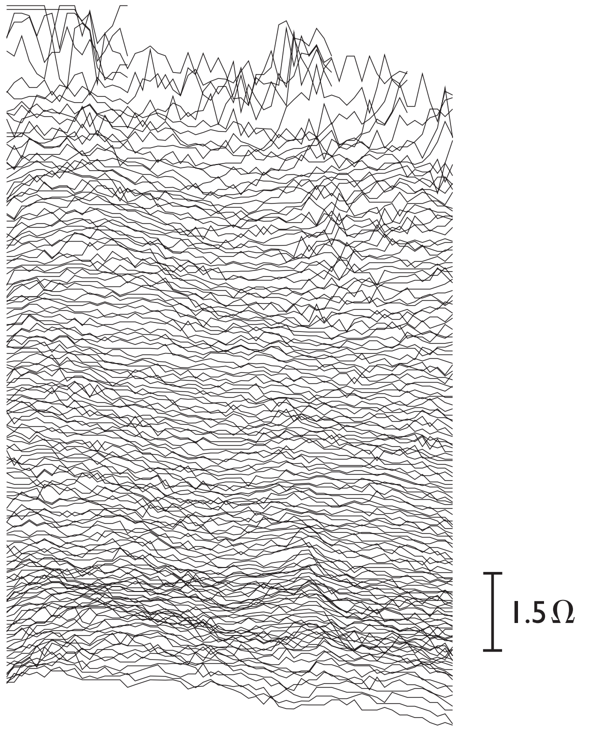
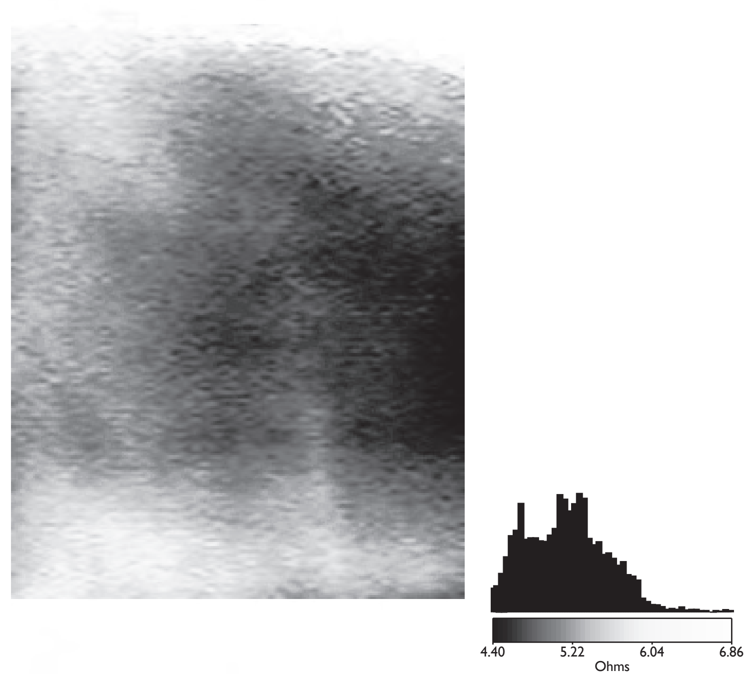
Twin probe earth resistance surveys of Area G, February 2008

Figure 14

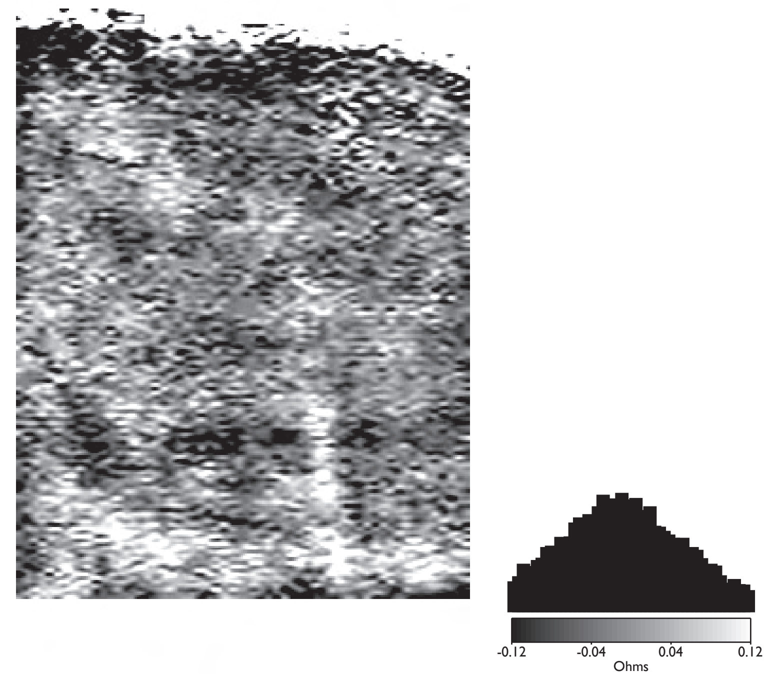
(A) Traceplot of raw 0.5m mobile probe separation data



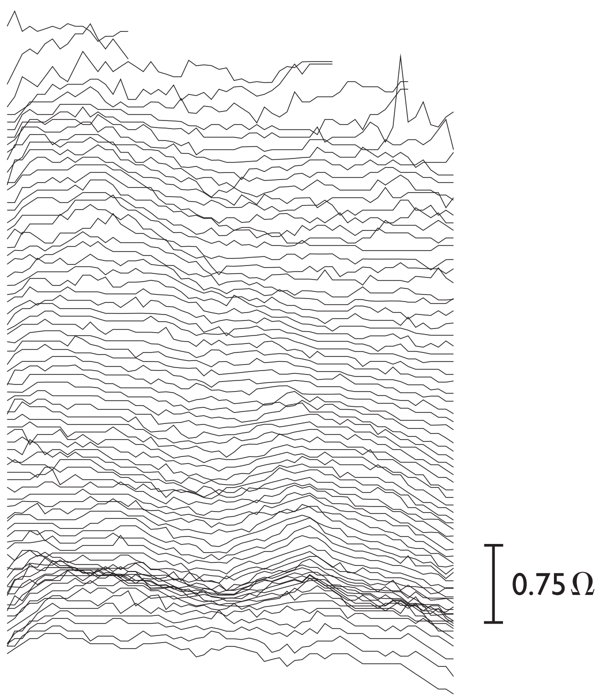
(B) Equal area greyscale image of raw 0.5m mobile probe separation data



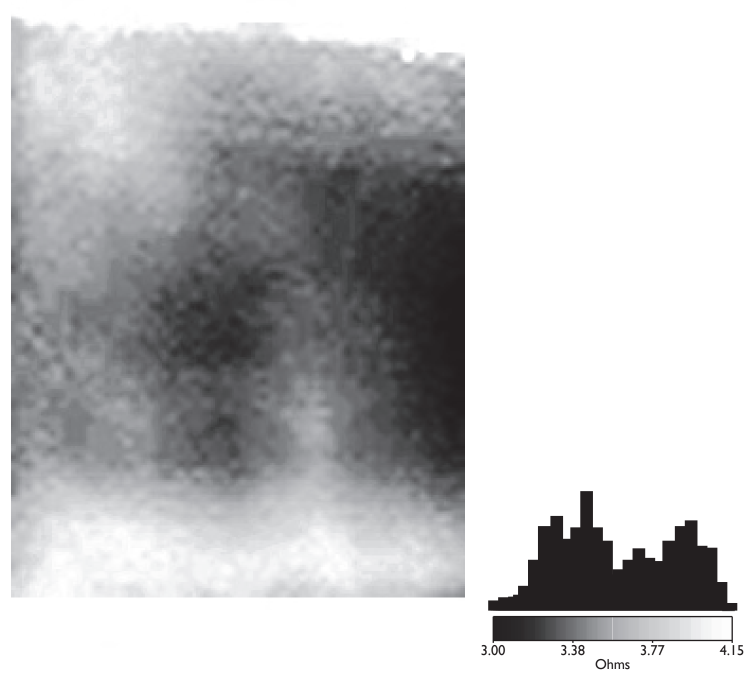
(C) Linear greyscale image of filtered 0.5m mobile probe separation data



(D) Traceplot of raw 1.0m mobile probe separation data

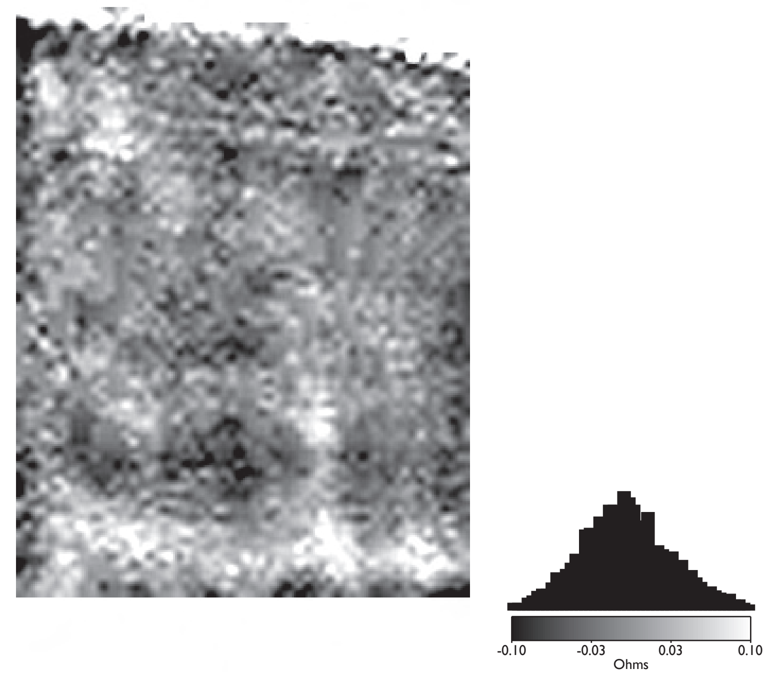


(E) Equal area greyscale image of raw 1.0m mobile probe separation data



N

(F) Linear greyscale image of filtered 1.0m mobile probe separation data



0 60m

1:1000

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