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Silbury Hill, Wiltshire: Report on Geophysical Survey, February 2001

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Summary

A geophysical survey using magnetic, earth resistance and ground penetrating radar (GPR) techniques was conducted on the summit of Silbury Hill, Wiltshire, to investigate the area surrounding the recently collapsed remains of an antiquarian excavation shaft sunk by the Duke of Northumberland in 1776. It was hoped that the survey would reveal evidence for any near-surface archaeological remains threatened by the continued collapse of the shaft and identify unstable areas of ground where further subsidence might be likely. Given the limited area available the results proved quite encouraging, with anomalies of interest identified in both the earth resistance and GPR data. However, these latter pit- and ditch-type anomalies do not appear to be related to the walled features recorded during the 1968 excavation on the summit of the monument. Results from the immediate vicinity of the collapse confirm the area of slumped ground to the S is highly unstable and liable to further subsidence at any time.

Keywords

Geophysical Survey

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SILBURY HILL, Wiltshire.

Report on geophysical survey, February 2001.

Introduction

A geophysical survey of approximately 0.09 ha was conducted on the summit of the Neolithic man-made mound of Silbury Hill, Wiltshire (National Monument Number: 21707) at the request of the regional Inspector of Ancient Monuments. In May 2000, an antiquarian excavation shaft dug by the Duke of Northumberland between 1776-7, opened up in the centre of the mound after a period of heavy rain. During December 2000 further collapses occurred, widening the top of the hole and leading to concerns over the stability of the monument. A programme of recording and monitoring was initiated by English Heritage, of which this geophysical survey forms a part. Past geophysical investigations at the site did not prove successful (McKim 1959) with particularly fruitless results following an earth resistance survey on the top of the mound during the 1968 excavations (Whittle 1997; pp20).

The aim of the survey was to investigate any anomalies in the immediate sub-surface using a variety of techniques on the summit of the monument to identify both significant archaeological activity and further areas of unstable ground that may also be liable to collapse.

Silbury Hill (SU 099 685) is constructed of compacted chalk blocks, thought to have been cut from the ditch around its base (Burl 1986: pp131). This lies over well drained calcareous silty soils of the Andover 1 and Coombe 1 association (Soil Survey of England and Wales 1983) developed over Middle Chalk (Institute of Geological Sciences 1974). At the time of the survey the hill was under grass and the ferrous chain-link fencing protecting the mouth of the hole had been removed leaving only the wooden support posts.

Method

Magnetometer survey

Magnetometry was chosen as the first survey technique to investigate the top of Silbury Hill. The survey was conducted over the single grid-square (Figure 1) using the standard method outlined in note 2 of Annex 1, but with a reduced traverse interval of 0.5m. Plots of the resulting data are presented as both an X-Y traceplot and a linear greyscale, at a scale of 1:250 on Plan A. The only corrections made to the measured values displayed in the plots were to zero-mean each instrument traverse to remove heading errors and to 'despike' the data through the application of a 2m by 2m thresholding median filter (Scollar *et al* 1990: pp 492) to reduce the detrimental effects produced by surface iron objects.

Earth resistance survey

A resistivity survey was conducted over the same area (Figure 1) using a Geoscan RM15 resistance meter, MPX15 multiplexer and PA5 mobile probe array in the Twin-Electrode configuration to simultaneously collect readings at mobile probe spacings of 0.5m and 1.0m. A sample interval of 0.5m x 0.5m was deployed for the 0.5m mobile probe spacing (shallow) and 0.5m x 1.0m for the 1.0m mobile probe spacing (deeper). Plots of the data sets are presented as both X-Y traceplots and linear greyscales, at a scale of 1:250 in Plan B.

Ground Penetrating Radar

A Pulse Ekko PE1000 console was used to collected GPR profiles with a 225MHz centre frequency antenna chosen to maximise the depth of penetration into the monument. A common mid-point (CMP) velocity analysis[1] was subsequently conducted with this antenna and confirmed that the velocity of the radar wavefront in immediate topsoil was ~0.059m/nS. However, analysis of hyperbolic diffraction tails within the survey data suggests the velocity within the compacted chalk beneath the topsoil was ~0.09m/nS. This latter velocity was therefore used to estimate the depth to reflection events in the recorded profiles. Individual profiles were subject to post-acquisition processing involving the adjustment of time-zero to coincide with the true ground surface, removal of any low frequency transient response (dewow) and the application of a spreading and exponential compensation (SEC) gain function to enhance late arrivals.

A total of 58 parallel NS profiles separated by 0.5m were collected over the site at a sample interval 0.05m (Figure 2). Selected profiles, showing significant anomalies, are presented in Plan D and amplitude time slices created from the entire data set are illustrated in Plan E as a series of false colour images (David and Linford 2000). Each amplitude time slice represents a vertical thickness of ~0.36m.

Results

Magnetometer survey *Plans A and C*

The magnetometer survey demonstrates a rather disturbed area with a considerable concentration of ferrous detritus both surrounding and immediately to the S of the current collapse. This disturbance is almost certainly due to a combination of litter accumulated by visitors to the summit, debris from the recent erection of fencing and the chicken-wire introduced from 1963 to stabilise the turf (Whittle 1997; pp20). Beyond this intense ferrous disturbance lie areas of less severe magnetic noise that may well be related to ferrous litter and perhaps the use of fire. However, this response does not necessarily imply an archaeological origin and may well be due to more recent camp-fires.

[1] Experimental determination of the velocity within the near surface chalk layer was considered through the method of inserting a high amplitude point reflector at a known depth in the exposed section within the collapsed shaft. However, due to concerns regarding the stability of the collapse and the necessity of obtaining further permissions this course of investigation was not attempted.

A single, highly tentative negative linear anomaly [1] is found to the N of the grid and is not replicated in any data from the other geophysical survey techniques. If genuine, it seems likely that this anomaly may represent an ephemeral surface feature.

Earth resistance survey *Plans B and C*

Results from the earth resistance survey have, apparently, proved slightly more fruitful than original 1968 investigation using the same technique. Both the shallow (0.5m mobile probe spacing) and deeper penetrating (1.0m mobile probe spacing) data indicate an increased resistance [2] towards the edge of the summit where the generally flat topography breaks onto the steep edges of the hill. This effect seems more pronounced in the shallow data suggesting it may well be due to a variation in topsoil depth thinning towards the edge of the summit (*cf* GPR results below). Further areas of high resistance are found in the immediate vicinity of the collapsed shaft [3] and a more discrete anomaly to the NE at [4]. The high resistance response surrounding the collapsed shaft is expected from similar earth resistance measurements collected close to open excavation trenches (*eg* Scollar *et al* 1990; pp350). However, the semi-circular anomaly due S of the collapse is of greater concern as it maps a series of fissures visible during the survey surrounding the edges of a partially slumped, highly unstable area of the site (Figure 2).

An intense area of low resistance is found to the S of the grid at [5] and correlates with anomalies in both the magnetic and GPR data sets. From comparison with these other responses this anomaly would appear to be related to ferrous material, possibly the chicken-wire reinforcement that apparently had such an adverse effect on the original (c1968) earth resistance survey. The more localised extent of [5] suggests that the chicken-wire was either concentrated to the S of the summit (where it is still partially visible) or has broken down over the rest of the monument. This latter hypothesis would explain the less intense low resistance values that mirror the areas of magnetic disturbance SE of the collapse.

A further low resistance anomaly [6] is found to the E of the collapse coinciding with an obvious topographic depression (Figure 2). The anomaly is most pronounced in the shallow data suggesting the maximum contrast in earth resistance is found close to the surface. The relationship between [6] and a more diffuse ditch-type anomaly [7] is unclear as both appear to lie with an annulus of low resistance surrounding the centre of the summit. However, both [6] and [7] appear to correlate with discrete anomalies in the GPR data.

Ground Penetrating Radar *Plans D and E*

Conditions on the summit of the monument were not ideal for GPR survey given the limited area available and considerable surface clutter due to the standing fence posts and necessary survey equipment. This has resulted in the presence of spurious air-wave reflections from the fence posts that are visible as a rectangular anomaly [8] in the very near surface data (eg 0-8nS and 8-16nS time slices; Plan E). In addition, the contrast between the short grass on the crown of the monument and the rough vegetation on the slopes of the monument is evident in the early reflections (8-16nS time slice) as a low amplitude anomaly [9] caused by reduced coupling between the antenna and the ground surface.

A prominent high amplitude anomaly [10] is also evident within the near surface data and it would appear from the nature of this response (Line 12.0; Plan D) that this is due to ferrous material – probably the chicken-wire netting laid in the 1960s referred to above (Whittle 1997; p20). However, the disturbance seen in the GPR data is highly localised and does not correspond exactly with either the widely dispersed area of magnetic disturbance or the more localised low resistance response [5]. The very early reflections also contain a high amplitude anomaly [11] associated with the observed fractures in the area of unstable ground immediately S of the current collapse (Plan D Line 20.5m and Plan E).

In general, the profiles collected in areas free of extraneous modern disturbance describe an undulating layer of high amplitude reflections composed of both semi-continuous horizontal facies and discrete hyperbolic responses (Plan D). The depth to this undulating layer may be estimated from the individual radar profiles where the initial horizontal response represents the air-wave and reflections from the ground surface. From the CMP velocity estimates the maximum topsoil depth would appear to be ~0.3m but this does vary quite considerably, particularly at the edges of the summit were the more easily weathered slopes demonstrate reduced soil cover. The layer of later reflections extends to a depth of ~2.5m (based on an estimated velocity of 0.09m/nS) below which the GPR signal is rapidly attenuated perhaps suggesting a more definite interface between the near surface and more deeply lying material at about this depth.

More significant anomalies appear to be cut through these near surface reflections and may be identified within the amplitude time slices presented in Plan E. These include a ditch-type response [12] to the N of the summit that becomes apparent in the 24-32nS time slice (~1m) and is still evident in the 64-72nS time slice (~3m). The response is recorded on a number of profiles across the centre of the site and can be seen as a discontinuity in the undulating layer with sloping edges in profiles at 12.0m and 20.5m (Plan D) and is replicated as a subtle low resistance anomaly [7]. A similar, but smaller anomaly [13] is recorded SW of the collapsed shaft but this is close to both the edge of the survey and to the ferrous disturbance [10] - factors which may question the fidelity of the data in this area.

A number of ephemeral pit-type responses are suggested both to the N [14] and W [15] of the shaft but do not extend to such a great depth, being all but extinguished by the 40-48nS time slice (~1.8m). Whilst the significance of these anomalies is difficult to determine their more discrete, pit-type nature suggests that they may represent the remains C18th tree planting reported by William Stukeley (Piggott 1985, *cf* Keevil and Linford 1997).

A concentrated layer of high amplitude response [16] is evident immediately NE of the current collapse and correlates with an area of increased earth resistance [4]. Whilst a more significant interpretation, such as a buried sarsen, cannot be ruled out[2] it seems equally likely that this response is related to the instability of the monument in the immediate vicinity of the collapse. Of greater significance is the pit-type response [17] immediately E of [16] that is associated with both a topographic depression (Figure 2) and a discrete low resistance response [6]. Anomaly [17] is first evident within the 24-32nS time slice and continues through the layer of high amplitude response suggesting a depth of ~2m based on the available velocity estimates. The apparent size of this latter anomaly (~2.5m diameter) suggests quite a substantial causative feature with similar dimensions to the original 1776 shaft.

[2] Sarsens were observed in the section of the collapse during the survey.

Conclusion

The results of the present geophysical surveys have proved more successful than would be expected from such a limited area with a poor history of similar investigations. It is unclear whether this is due to the decay of the chicken-wire netting, identified as a significant impediment to the original earth resistance survey, or the use of more recent geophysical instrumentation. Whilst both pit- and ditch-type anomalies have been revealed these do not appear to be related to the arcs of walling revealed during the 1968 excavation (Whittle 1997; Fig 17 and Plates 7 and 8). Indeed, even the location of this former excavation trench has eluded relocation through the geophysical techniques applied. This is, perhaps, unsurprising given the modest physical contrast that would occur between a chalk rubble back-fill packed between consolidated chalk construction walls. However, the GPR profiles do suggest a contrast at a depth of 2.5-3m between the near-surface conditions and those below this depth.

The two most significant anomalies revealed by the survey are the pit-type response [17] and the ditch-type anomaly [12] that apparently extend to quite a considerable depth (>2m). These do not appear to be related to the location of the 1968 excavation trench and may possibly represent significant archaeological features although probably not voids.

Of much greater concern is the apparent instability associated with the deformed area immediately S of the current collapse. The geophysical surveys reveal anomalies associated with fissures surrounding the edge of this area and suggest that further subsidence into the collapsed shaft is likely to occur at any time in the near future.

Surveyed by: A David
N Linford
L Martin
L Murray (volunteer)
A Payne

T Cromwell (topographic survey)
B Thomason (GPS survey)

Date of survey: 28/2/2001

Reported by: N Linford
L Martin

Date of report: 14/3/2001

Archaeometry Branch
Centre for Archaeology
English Heritage.

References

Burl, A., 1986, *Prehistoric Avebury.* Yale University Press. London.

David, A. and Linford, N., 2000, Physics and Archaeology, *Physics World*, **13**, No. 5, pp27-31.

Institute of Geological Sciences, 1974, Marlborough, England and Wales, Sheet 266, 1:50,000.

Keevil, G. D. and Linford, N., 1997, Landscape with gardens: aerial, topographical and geophysical surveys at Hamstead Marshall, Berkshire, in *There by Design: Field Archaeology in Parks and Gardens*, (*ed.* P. Pattison), British Archaeological Report, British Series, **267**, pp13-22.

McKim, F. R., 1959, An attempt to locate a burial chamber in Silbury Hill, *Wiltshire Archaeological Magazine*, 57, pp176-8.

Piggott, S., 1985, *William Stukeley: an eighteenth century antiquary*, Thames and Hudson, London.

Scollar, I. Tabbagh, A. Hesse, A. and Herzog, I. (eds.), 1990, *Archaeological Prospecting and Remote Sensing*. Cambridge.

Soil Survey of England and Wales, 1983, Soils of England and Wales, Sheet 5, South West England.

Whittle, A., 1997, *Sacred Mound, Holy Rings Silbury Hill and the West Kennet palisade enclosures a Later Neolithic complex in north Wiltshire*, Oxbow Monograph, **74**, Oxford.

List of enclosed figures.

Annex 1: Notes on standard procedures

1) **Resistivity 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 resistivity 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 (Ù). 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 the Centre for Archaeology 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 North. 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. However, the magnetometer is always kept facing in the same direction, regardless of the direction of travel, to minimise heading error.

   Unless otherwise stated the measurements are made with a Geoscan FM36 fluxgate gradiometer which incorporates two vertically aligned fluxgates, one situated 0.5 metres above the other; the bottom fluxgate is carried at a height of approximately 0.2 metres above the ground surface. The FM36 incorporates 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 the Centre for Archaeology 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.

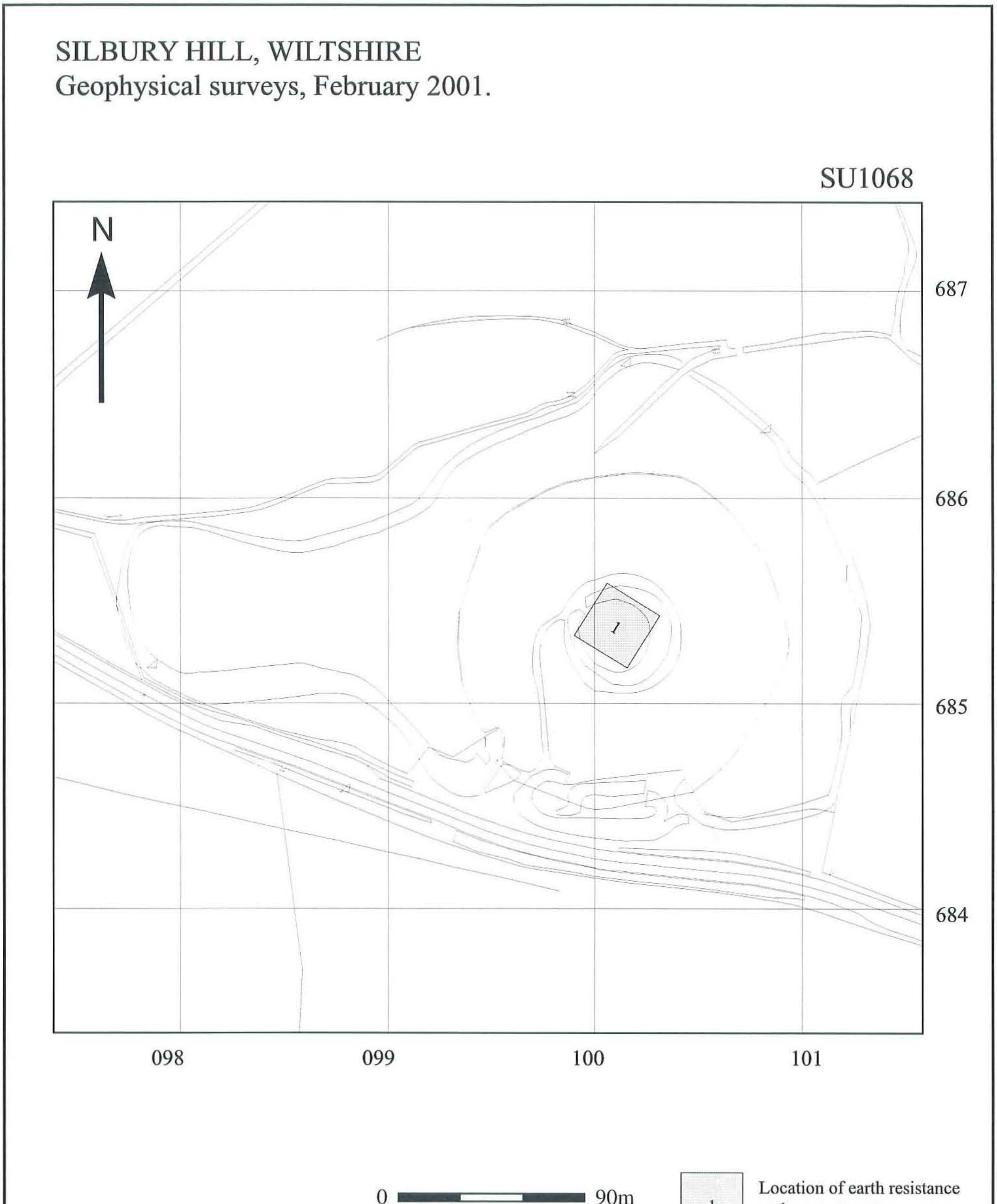


Figure 1; Silbury Hill, Wiltshire, *Location of geophysical surveys, February 2001.*

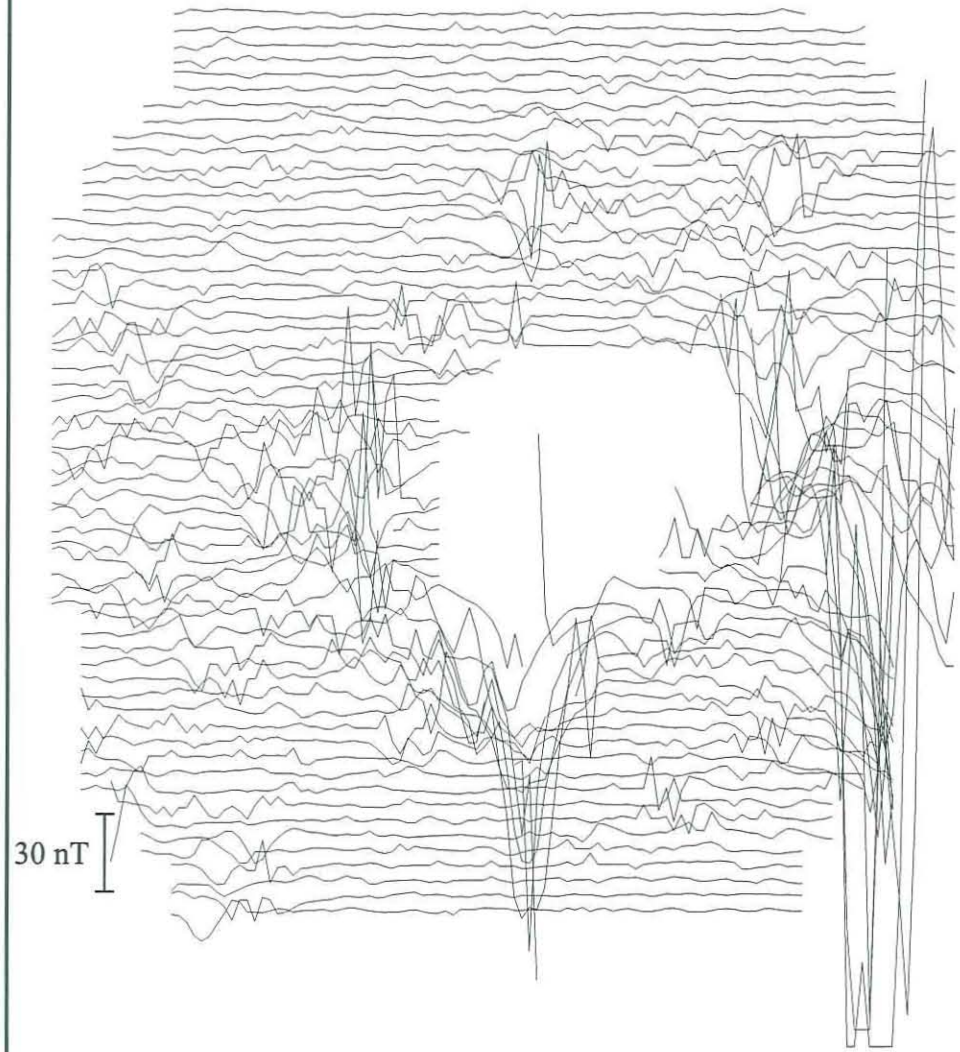
SILBURY HILL, WILTSHIRE

PLAN A

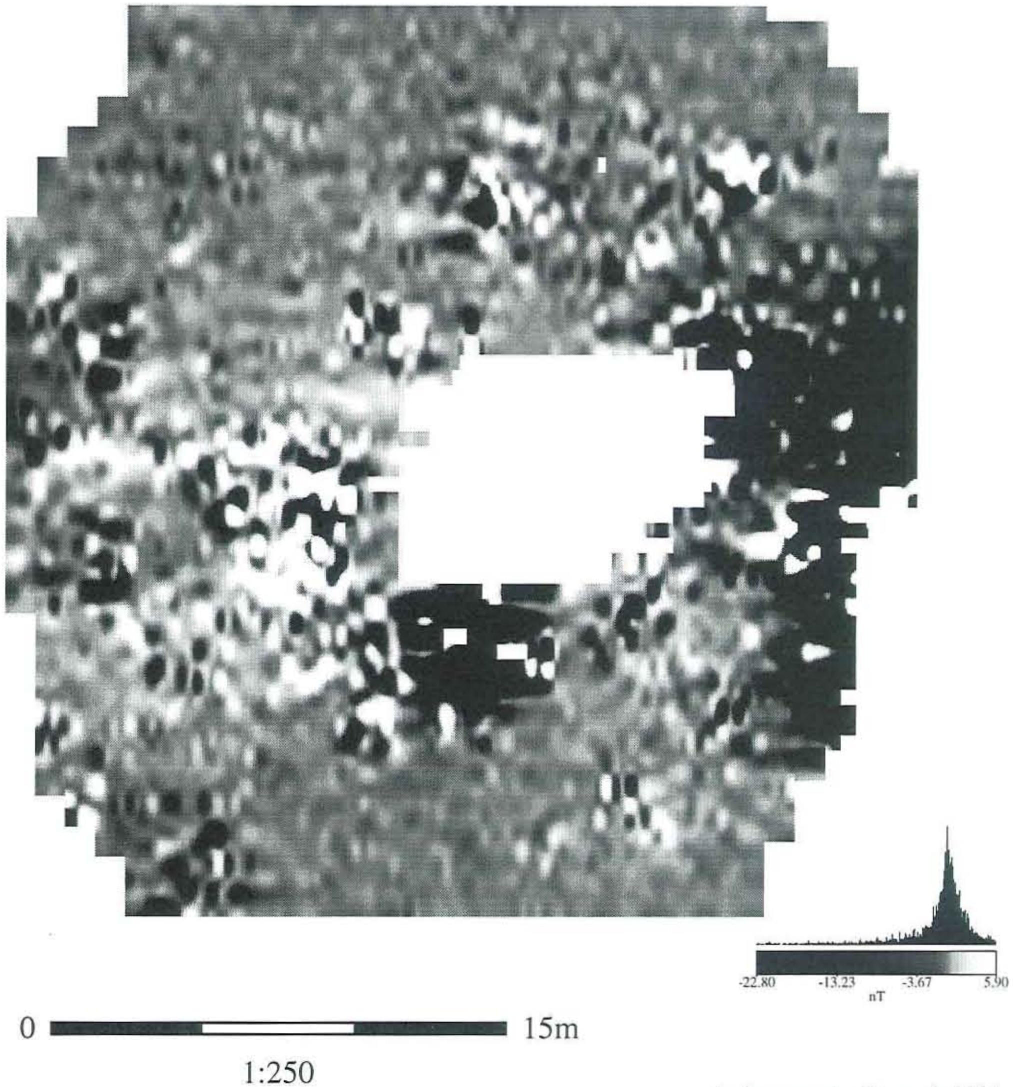
Magnetometer survey, February 2001.

N

1) Traceplot of raw despiked magnetometer data.



2) Linear greyscale of despiked magnetometer data.



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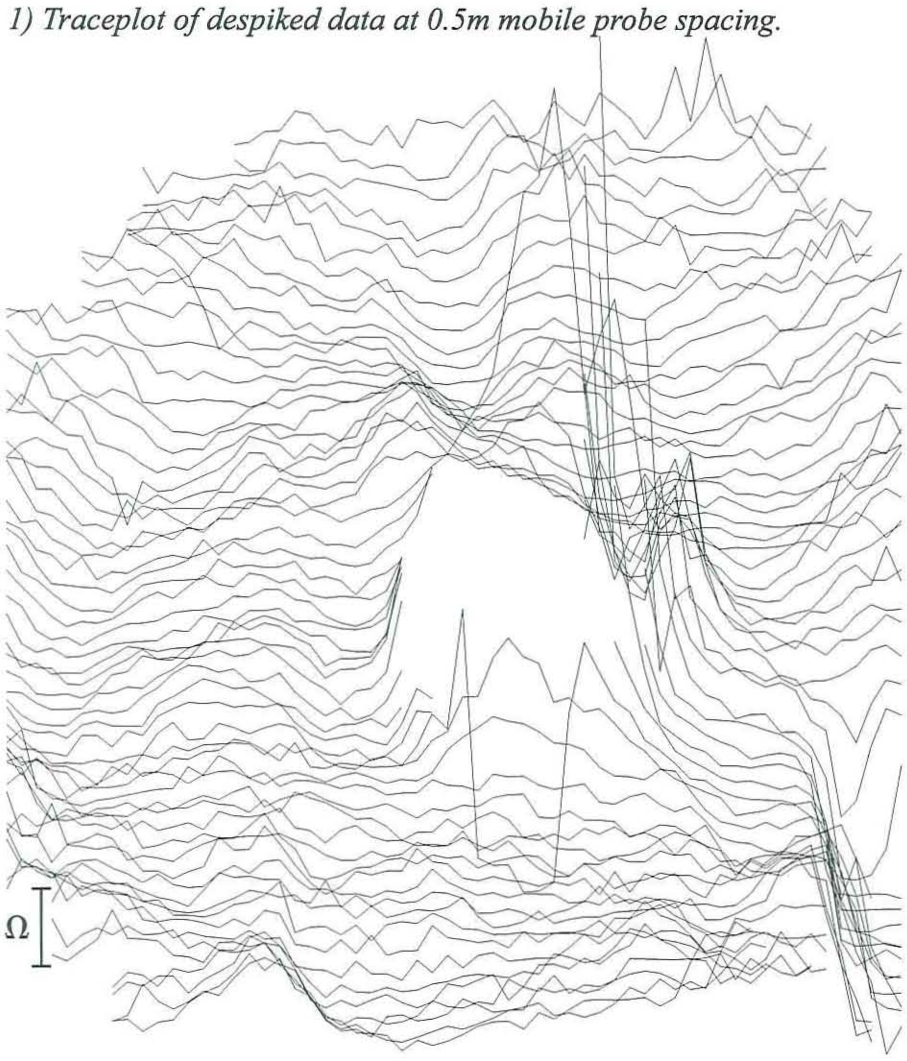
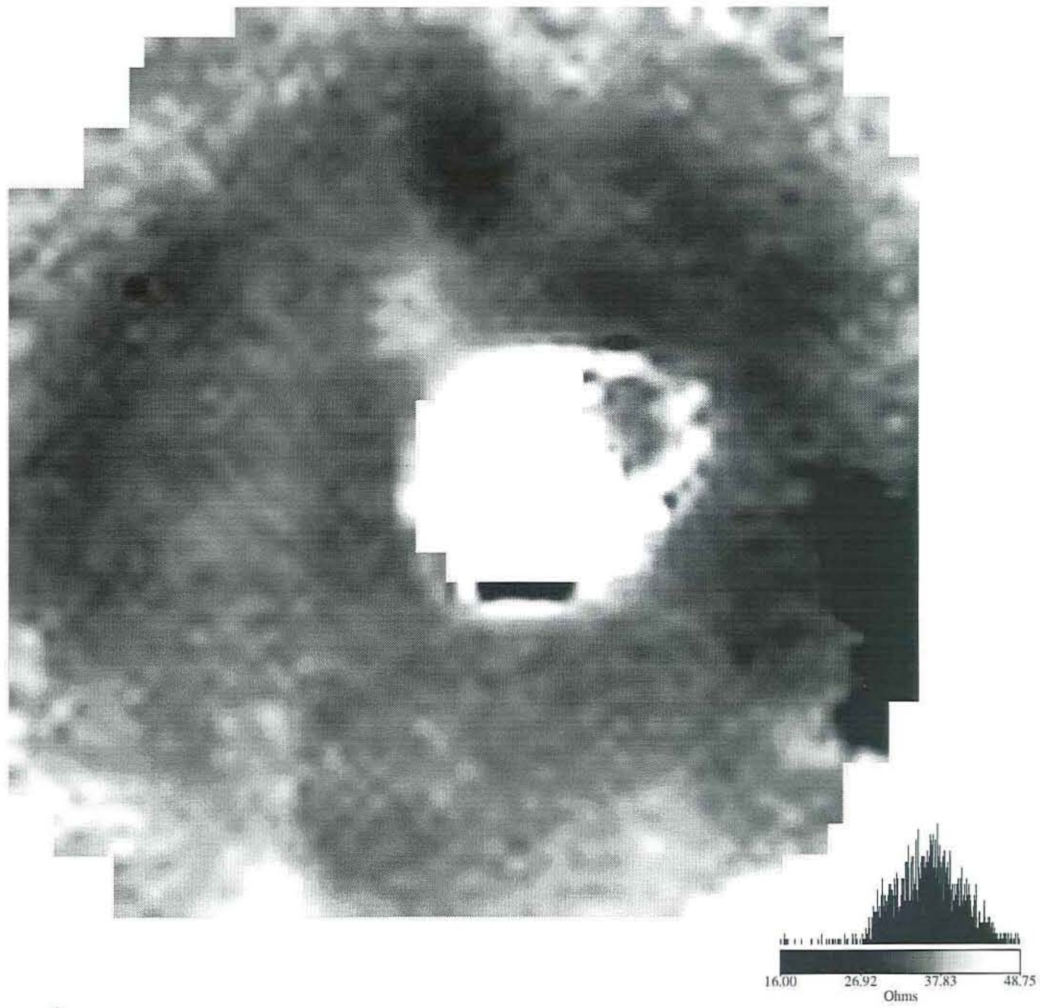
Resistivity survey, February 2001.

PLAN B

1) Traceplot of despiked data at 0.5m mobile probe spacing.

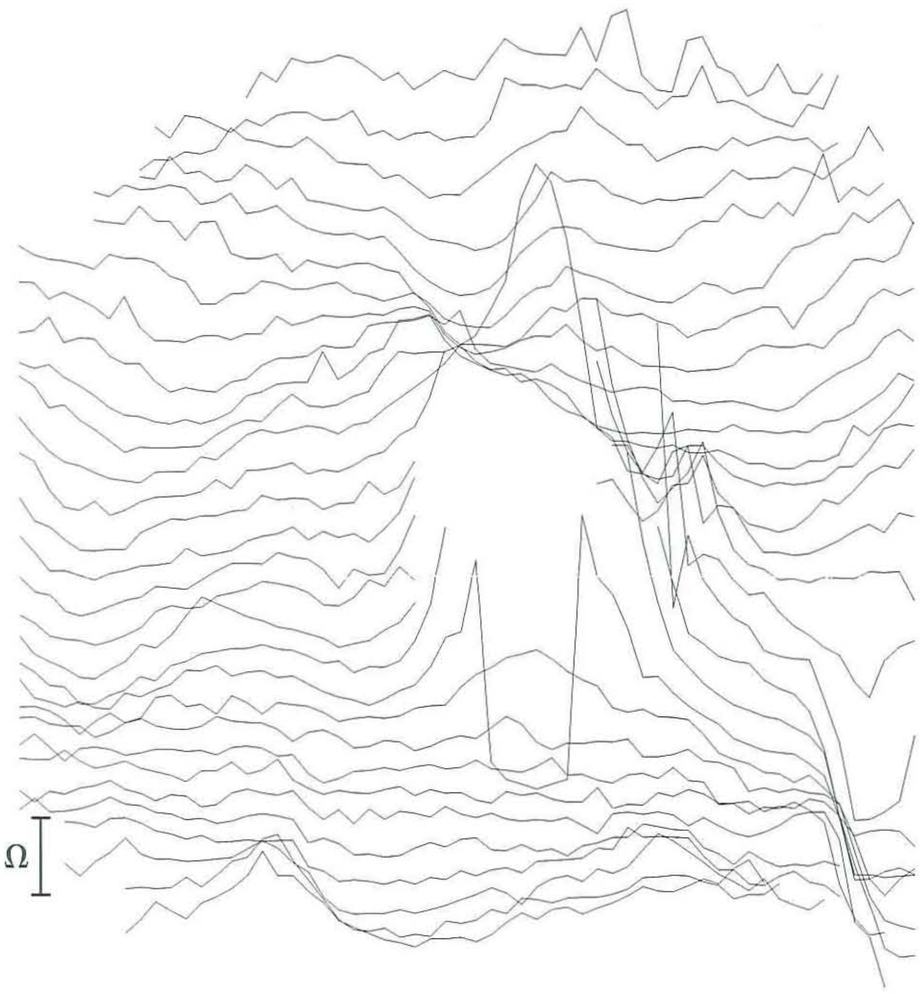


2) Linear greyscale of despiked data at 0.5m mobile probe spacing.

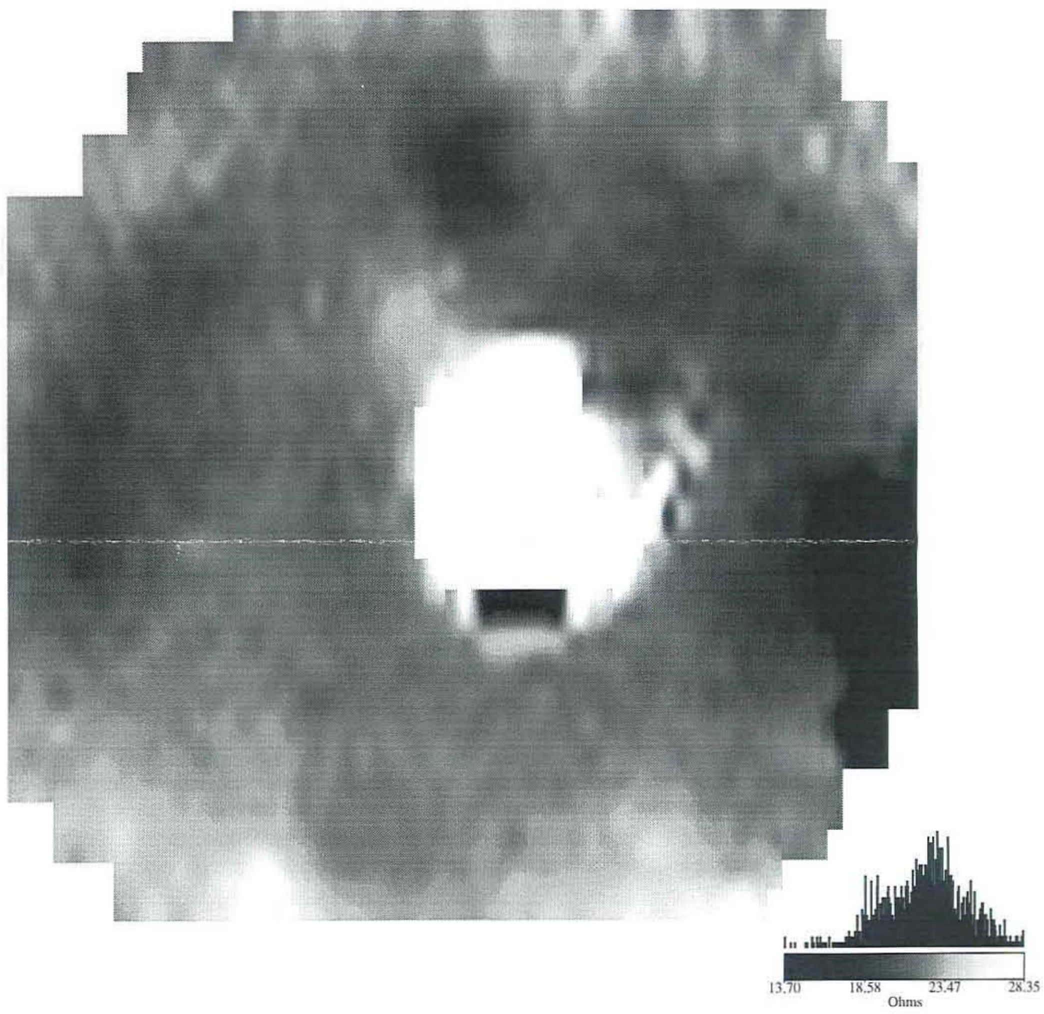


N

3) Traceplot of despiked data at 1.0m mobile probe spacing.



4) Linear greyscale of despiked data at 1.0m mobile probe spacing.



0 15m

1:250

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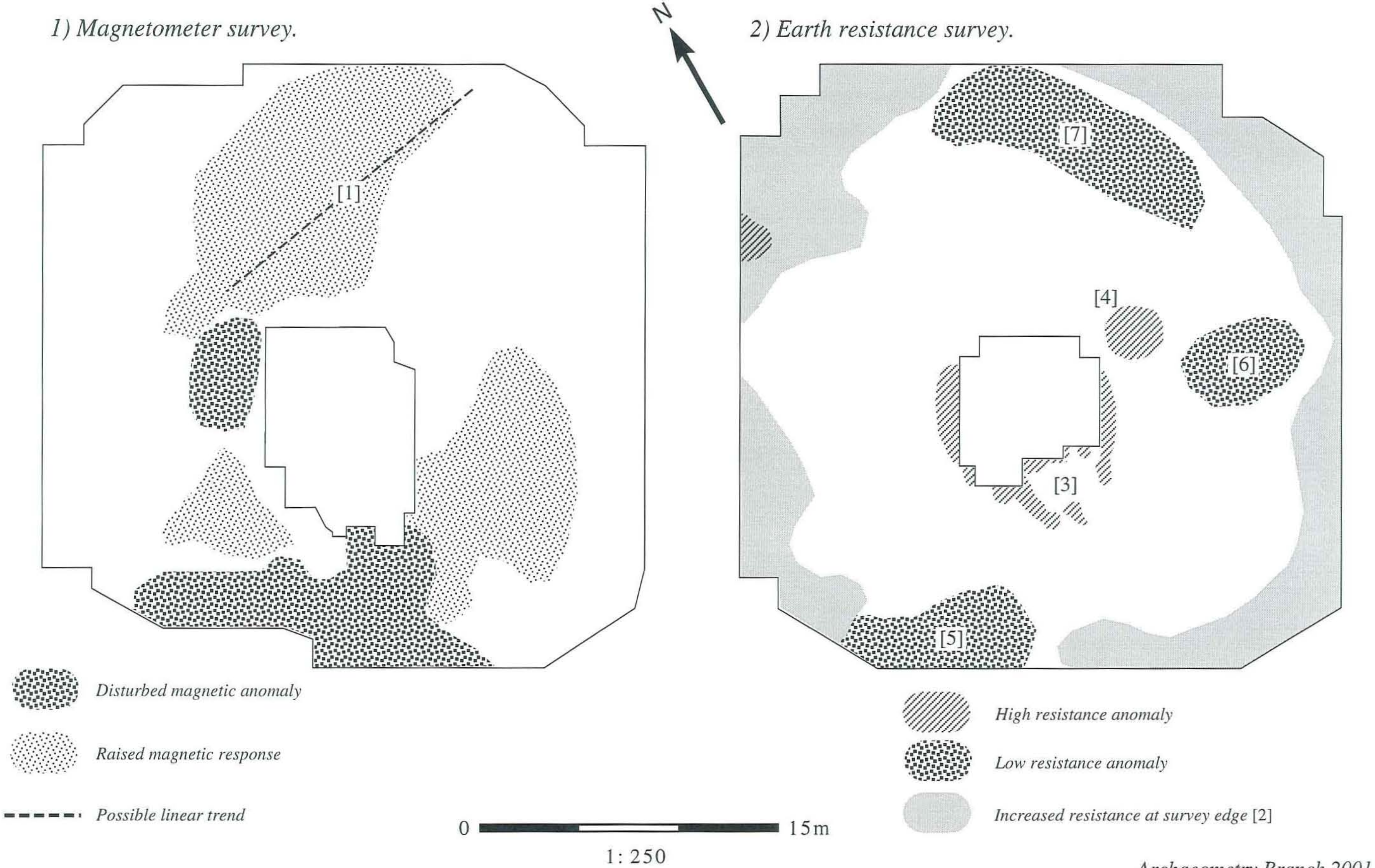
PLAN C

Graphical summary of significant geophysical anomalies.



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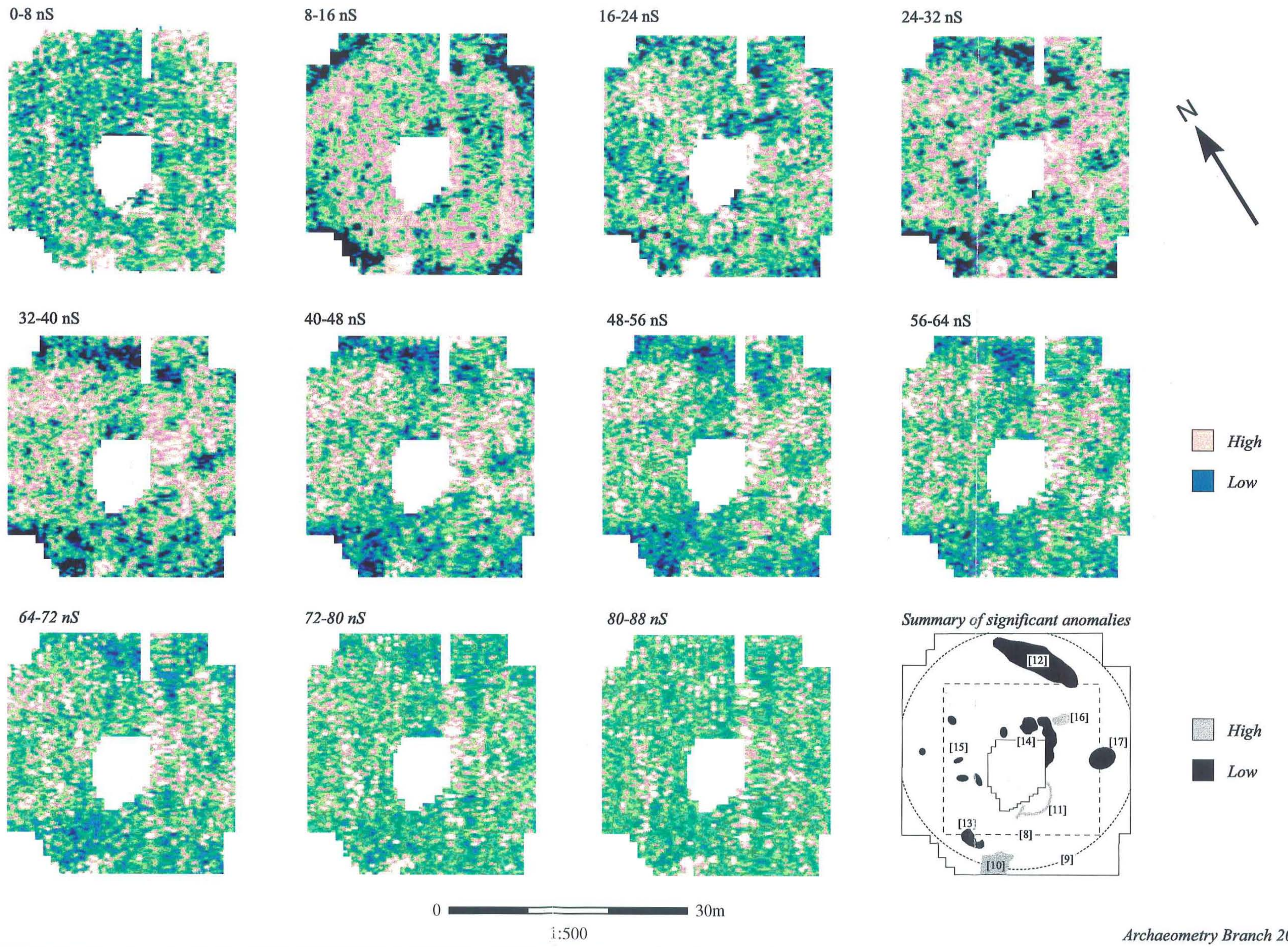
GPR Survey, February 2001

PLAN E

Histogram equalised amplitude time slices



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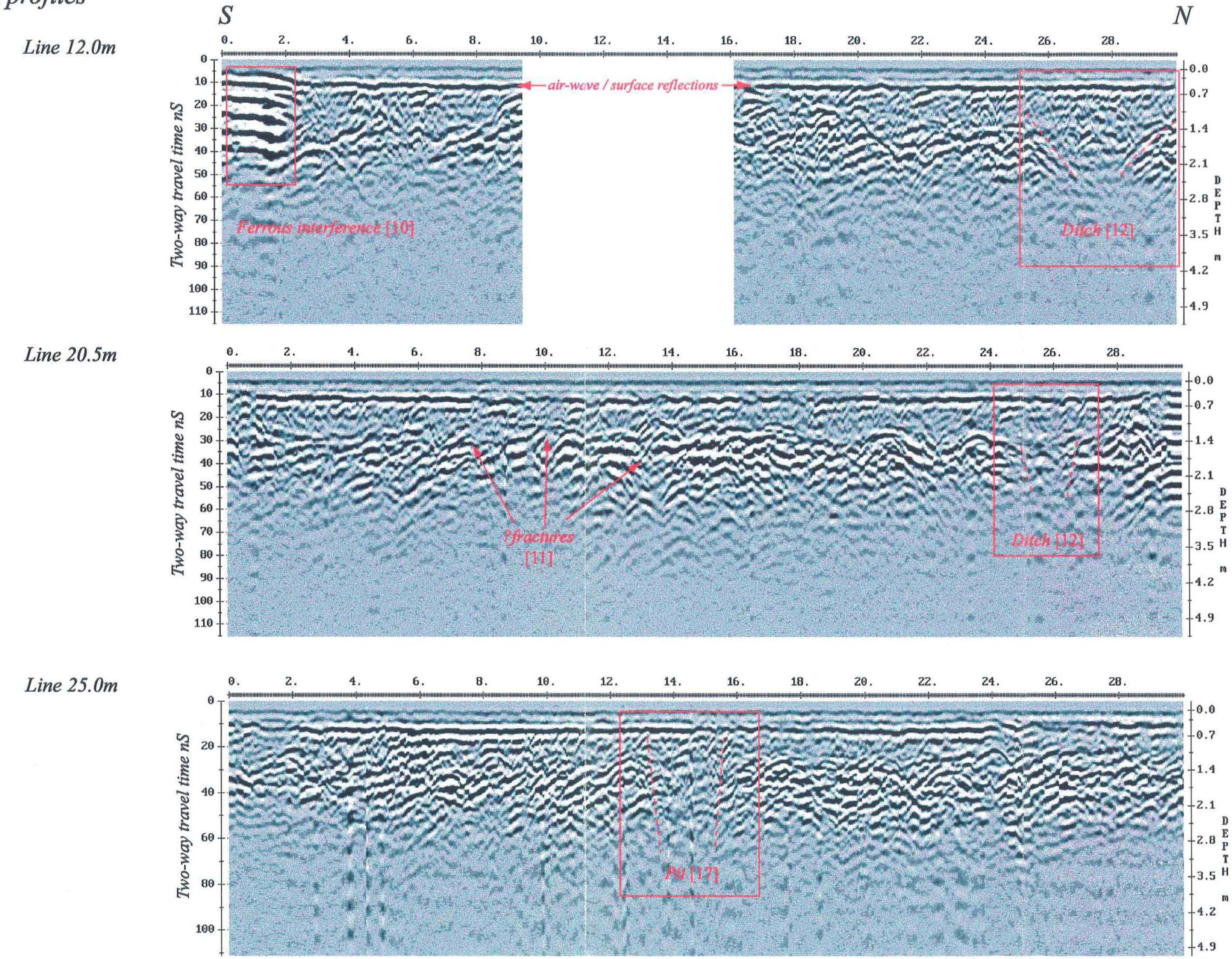
GPR Survey, February 2001

PLAN D

Representative GPR profiles



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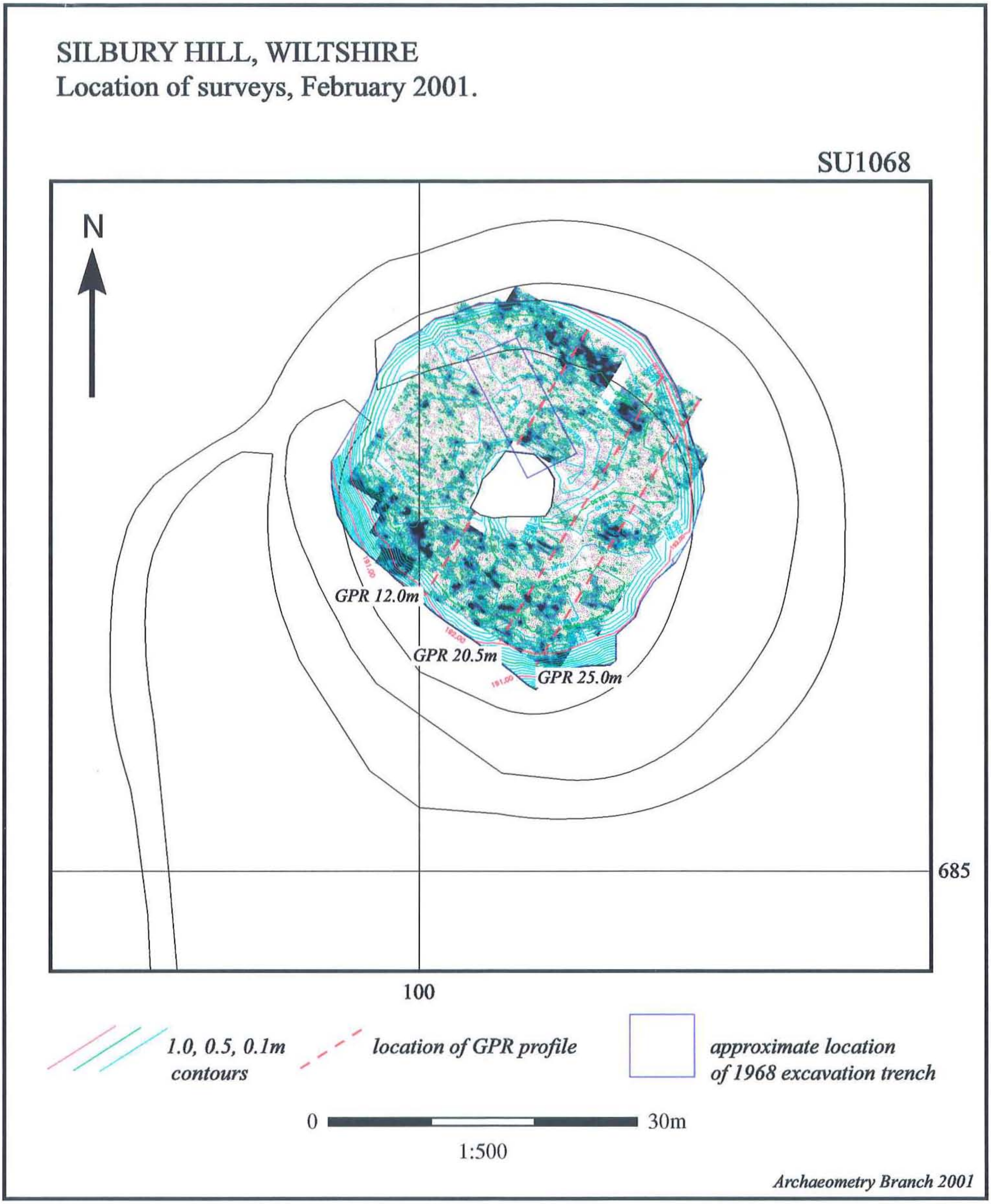

Figure 2; Silbury Hill, Wiltshire, *Detailed location plan showing the position of representative GPR profiles and the results of the topographic survey superimposed over the 32-40nS GPR time slice.*