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

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Summary

An electrical imaging survey 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 occur. Three trial profiles were also carried out on the flank of the hill. This work was intended to augment previous geophysical survey carried out at Silbury Hill by the Centre for Archaeology in February 2001. The survey detected a number of anomalies on the summit of the hill, two of which corresponded to features detected in trial trenches dug in April 2001. However, the interpretation of other anomalies is equivocal, and the suggestion of a further possible shaft is very tentative. One of the profiles on the flanks of the hill was impaired by wire mesh that had been inserted into the turf to protect it from erosion. However, the profile over the top of the Merewether tunnel did suggest a less homogenous structure to the chalk, possibly due to the tunnelling.

Keywords

Geophysics

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SILBURY HILL, Wiltshire.

Report on geophysical survey, June 2001.

Introduction

In June 2001 a number of electrical profiles were carried out on the summit and flanks of the Neolithic man-made mound of Silbury Hill, Wiltshire (National Monument Number: 21707) at the request of the Silbury Hill Project Board. This followed the unexpected reopening, after a period of heavy rain in May 2000, of an antiquarian excavation shaft dug down into the centre of the mound by the Duke of Northumberland between 1776-7. During December 2000 further collapses occurred, widening the top of the hole at the summit and leading to concerns over the general stability of the monument. A programme of recording and monitoring was initiated by English Heritage, of which this geophysical survey forms a part. It follows an earlier geophysical survey, carried out in February 2001, which used magnetometry, earth resistance and ground penetrating radar to examine the summit plateau of the mound (Linford and Martin 2001).

The aim of the further work reported below was to assess the value of electrical imaging to the detection of any archaeological features, voids or areas of structural weakness, to a depth of several metres below the summit and flanks of the mound. If obtainable, such information might have a significant bearing upon the deployment of more invasive investigations (eg placement of boreholes prior to seismic survey) and upon the choice of necessary remedial measures.

The upper part of 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). The mound 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 temporary ferrous chain-link fencing protecting the mouth of the hole at the summit had been removed leaving only the wooden support posts. The weather was dry and hot while the work was being carried out with the occasional thundery shower.

The imaging survey was preceded independently by the excavation of two archaeological evaluation trenches which were designed to assess and record the archaeological potential of the hilltop (McAvoy in prep). These trenches were backfilled by the time of the survey.

Method

Profiles on the summit of the hill

General information about the electrical profiling technique may be found in Annex 1, note 3. At Silbury Hill, electrical profiles were formed by laying out up to 50 electrodes in a straight line, one metre apart, and connecting these via multi-core cables to a multiplexed earth resistance meter. Fourteen such profiles were laid out parallel to each other and spaced two metres apart, with a further four orthogonal profiles to act as tie lines (Figure 1). The number of electrodes used in each profile varied as the available space was constrained by the shape of the summit of the hill. Earth resistance measurements were made with a Campus Geopulse 50 earth resistance meter, driven using Campus Imager50 software. As surface topography was significant, the exact location and height of each electrode was established using and EDM, for later processing.

Profiles on the flanks of the hill

Three profiles were laid out running from the top of the hill to its base (see Figure 1) to test the electrical response that could be obtained. The first profile (Flank01) followed the intended course of a dragline that will be used to haul equipment to the summit of the mound for the proposed remedial work and drilling mentioned in the introduction. The line of the second (Flank02) was chosen to coincide approximately with the course of tunnels dug laterally into the hill in 1849 and 1968-9: Whittle 1997, Fig 6). The third profile (Flank03) was intended as a control.

Flank01 consisted of 64 electrodes separated at 1.1 metre intervals and earth resistance measurements were made with a Campus Tigre 64 meter. The unusual electrode separation was chosen to allow the full length of the hill to be surveyed using 64 electrodes, the maximum that could be used simultaneously with the equipment available, without the necessity of carrying out a roll-on survey (see below).

Flank02 was measured by first laying out 50 electrodes at 1.0 metre separation, beginning at the summit of the hill and taking all possible resistance measurements. A roll-on survey was then conducted by taking the two electrodes from the top end of the profile and using them to extend the bottom end by two metres. All possible measurements involving these two new electrode positions were then recorded. This process was repeated ten times to produce a final section 70 metres long. A Campus Geopulse 50 meter was used to collect the earth resistance measurements.

Flank03 was measured in the same way as Flank02 but the final length of the section was only 60 metres owing to time constraints. With all the flank profiles an EDM was used to record the exact position and height of each electrode.

Electrode configuration and processing

For all the profiles the Wenner electrode configuration was chosen for taking the earth resistance measurements owing to its good signal to noise ratio. All the profiles were processed using Geotomo Software's Res2Dinv package. XYZ output from this package was read into Geosoft's OASIS Montaj software for presentation of the profiles with the correct topographic aspect. The OASIS software was also used to produce horizontal depth-slices through the parallel profiles carried out on the summit of the hill (Figures 3 and 4).

Results

Profile on the summit of the hill

Figure 2 shows the results of the fourteen parallel profiles measured on the summit of the hill depicted as colour scale plots. In this figure the northernmost profile (labelled 00 in Figure 1) is at the top of the page whilst the southernmost (26) is at the bottom. Figure 3 depicts the same profiles as greyscale plots, whilst Figure 4 shows colour scale plots of horizontal slices taken through these stacked profiles. Figure 5 shows colour scale plots of the four north-south profiles (labelled NS04, NS07, NS10 and NS19 in Figure 1) depicted using the same colour assignments that were used in Figure 2. An interpretation plan of the main anomalies detected on the summit of the hill is depicted in Figure 9. All these Figures are at a scale of 1:500.

Examination of Figures 4a-c suggests that the ground at the summit of the monument to a depth of three metres is relatively dry with an average resistivity in excess of 200•m. Areas of particularly high resistivity (>350•m) are identifiable (marked in red on Figure 9) and it is possible that these may be responses to structural features such as the retaining walls of laid chalk blocks noted in previous excavations (Whittle 1997; Fig 17 and Plates 7 and 8). Some corroboration for this conjecture may be noted in profile NS07 (see below), where a high resistance anomaly was detected at a point where the top of one of the chalk walls was noted in the recent excavation trench (F McAvoy *pers. comm.*). However, the anomalies are somewhat amorphous in outline and do not clearly reflect the pattern of arcing walls reported by Whittle. This is probably due to the difficulty of detecting chalk block structures within a substrate of chalk rubble; the contrast in electrical properties being so slight as to make the task almost impossible. Nonetheless, if these anomalies are indeed related to the retaining walls then examination of Figure 4 suggests that they extend downward to depths of up to 2.5m.

Two further high resistance anomalies have been marked on Figure 9 (yellow), the largest of which seems to cut one of the anomalies discussed above. The raised resistivity here (> 350•m) may in part be a response to the recent excavation, and to the walling encountered, but the effect extends to a depth of about 3.5m. Close to the hole caused by the collapsed shaft, the high readings could represent related drying out or cracking, with an implication of structural instability. However, the presence of sarsen blocks (noted in the section of the collapse) might also have caused raised resistance.

The smaller of the two high resistance anomalies appears in plan as an ellipse about 3 to 4.5m in diameter. It is cut in section by profile 06 (4^{th} down in Figure 2), where it has a resistivity greater than 400 •m. It is visible in Figures 4b-e, so possibly extends vertically to a depth of up to 5m and could thus represent a pit or shaft. However, interpretation of this anomaly (as for others) is difficult as it is not possible to distinguish it completely from overlapping anomalies.

At depths of 3-6m (Figures 4d-f) the average resistivity is lower, probably due to an increased volumetric water content in the chalk pore space. Resistivity is particularly low (< 50 •m) at the southern side of the summit (blue on Figure 9). This possible concentration of moisture may reflect the pattern of drainage from the summit of the mound although it is not clear whether or not any structural instability is implied.

Figure 5 depicts the four orthogonal north-south profiles carried out as a check on the above results. Two of these profiles (NS04 and NS07) intersect features noted during the recent excavations on the summit (F McAvoy *pers. comm.*). NS04 crosses a depression in the ground surface where an underlying pit was identified. Analysis of the profile suggests that this pit, which appears as a low resistance anomaly, extends to a depth of ~1.25-1.5m.

Profile NS07 cuts one of the chalk retaining walls, which was encountered at a depth of 0.2m in the excavation. It can be seen that there is indeed a high resistivity (> 400 •m) anomaly near the surface at the point marked (Figure 5), which extends downwards to a depth of about 2m.

Profiles on the flanks of the hill

Figures 6-8 depict the three profiles measured down the flanks of the hill. Figure 6 shows profile Flank01, its location chosen to coincide with the proposed route of a dragline to haul equipment to the top of the hill during the forthcoming drilling and remedial work. Unfortunately, it was discovered that wire mesh had been inserted in the late 1960s, under replaced turf, to stabilise the surface in this area. The wire caused shorting of the electrical current between the electrodes, particularly affecting the shallower depth measurements – resulting in impossibly low resistivities being recorded. This has lead to an extreme degree of noise in the measured resistivity section and a poor RMS error (39.71%) in the inversion. Hence, the colour scale in Figure 6 is different to that used in Figures 7 and 8 and the resistivity values depicted for this section should be treated as relative indications only.

A high resistivity region is apparent near the top of Flank01 beneath the break of slope caused by the terrace near the summit. This may be a response to the presumed ziggurat-like construction of the monument, where a corner of one of the horizontal layers of chalk blocks is close to the surface at this point. A second high resistivity area is apparent about two thirds of the way down (42m), close to where the profile crossed the path that spirals up the hillside. This may have the same cause as the high resistivity region higher up. Separating these two areas of high resistivity is an area of low resistivity stretching from about 27m to 40m from the top of the profile. It is possible that this anomaly is simply caused by the shorting of electric current through the wire mesh. However, if not, then this represents the area with the least support from the underlying chalk structure.

Profile Flank02 is depicted in Figure 7 and its location was chosen to run over the top of the entrances to the Merewether and Atkinson tunnels (Whittle 1997, Figure 4). A large, high resistance anomaly has again been detected near the top of the profile and this too may be a response to a construction layer. Comparison with profile Flank03 (Figure 8) shows that the subsurface below Flank02 has a more uneven resistivity distribution and a much lower average resistivity. This may be a symptom of structural instability associated with the tunnels beneath this profile, but this is conjectural. Of possible concern is the very high resistivity (> 500 •m) area about 29m from the top of the profile which may represent a void.

Conclusions

The results of the electrical imaging survey on the Silbury Hill are very difficult to interpret with confidence and it remains uncertain what significance can be placed on the anomalies identified, as was the case with the earlier geophysical surveys (Linford and Martin 2001).

The top 3m of the sub-surface below the summit plateau is dominated by a shifting pattern of high resistance which does not conform to any obvious structural pattern as predicted by previous excavation. Where the profiles cut the CfA test excavations of April 2001 (profiles NS04 and NS07), there has been some success in matching anomalies with archaeological features, but variations elsewhere are difficult to explain. High resistance is detectable to depths of 5m and it is possible that one persistent anomaly could represent an unidentified shaft. Other areas of high resistance may be caused by partial detection of structural remains, sarsen blocks, former excavations, and/or proximity to the current exposure.

There is some broad correlation between the shallower two horizontal slices of the profiles on the top of the hill (Figures 4a and b) and the earlier twin-electrode resistivity survey (Linford and Martin 2001, Plan B). However, this correlation is at the level only of broad regional trends and the specific anomalies identified by the two surveys are generally different. This poor correlation may well be a result of the changes in soil moisture distribution between the two episodes of fieldwork. Likewise, comparison of the resistivity imaging data with the GPR survey (ibid Plan E) may also have been compromised by changes in moisture regime. The July survey was undertaken in hot and mostly dry conditions, whilst the February survey was conducted during a winter of exceptional rainfall. Such contrasting field conditions might help explain why, for instance, the GPR data did not record a significant anomaly over the possible shaft mooted above, but is in general agreement with the high resistance near the northern edge of the collapse – a possible area of weakness. The resistivity imaging has provided a greater depth of penetration than the foregoing GPR survey, and records substantially lower resistance, and hence presumably a greater moisture content, at depths in excess of 4m from the surface, concentrating towards the south. Any implications leading from this observation, on the structural integrity of the mound, are uncertain.

It has not been possible unequivocally to identify any voids in the electrical profile data but this stems from the difficulty in defining the resistivity signature that a void might be expected to exhibit. An air filled void could present itself as a very high resistivity anomaly but if it became filled with rubble or water it might then have a lower resistivity than its surroundings. A possible void under the flank of the hill is indicated by the high resistance anomaly about 29m down Flank02 and this might perhaps be the result of the disturbance caused by tunnelling below it.

Overall, these results , whilst suggestive, are far from definitive and the above conclusions are largely tentative and open to conjecture. Given the nature of the mound, so far as this is known, and the novelty of applying the methodology in such circumstances, this is probably not surprising. The fieldwork was both arduous and very time consuming - so any future comprehensive coverage of the whole mound, would not be a light undertaking. In view of this and the highly ambiguous results of this trial survey further electrical imaging, for the present, is not recommended.

Surveyed by: P Linford Date of survey: 25/6 to 5/7/2001
L Martin
A Payne
F McAvoy
A McCallum (Conservation Engineering)

T Cromwell (assistance with GPS)

Reported by: P Linford Date of report: 8/8/2001

Archaeometry Branch
Centre for Archaeology
English Heritage.

Acknowledgements

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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 (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 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.

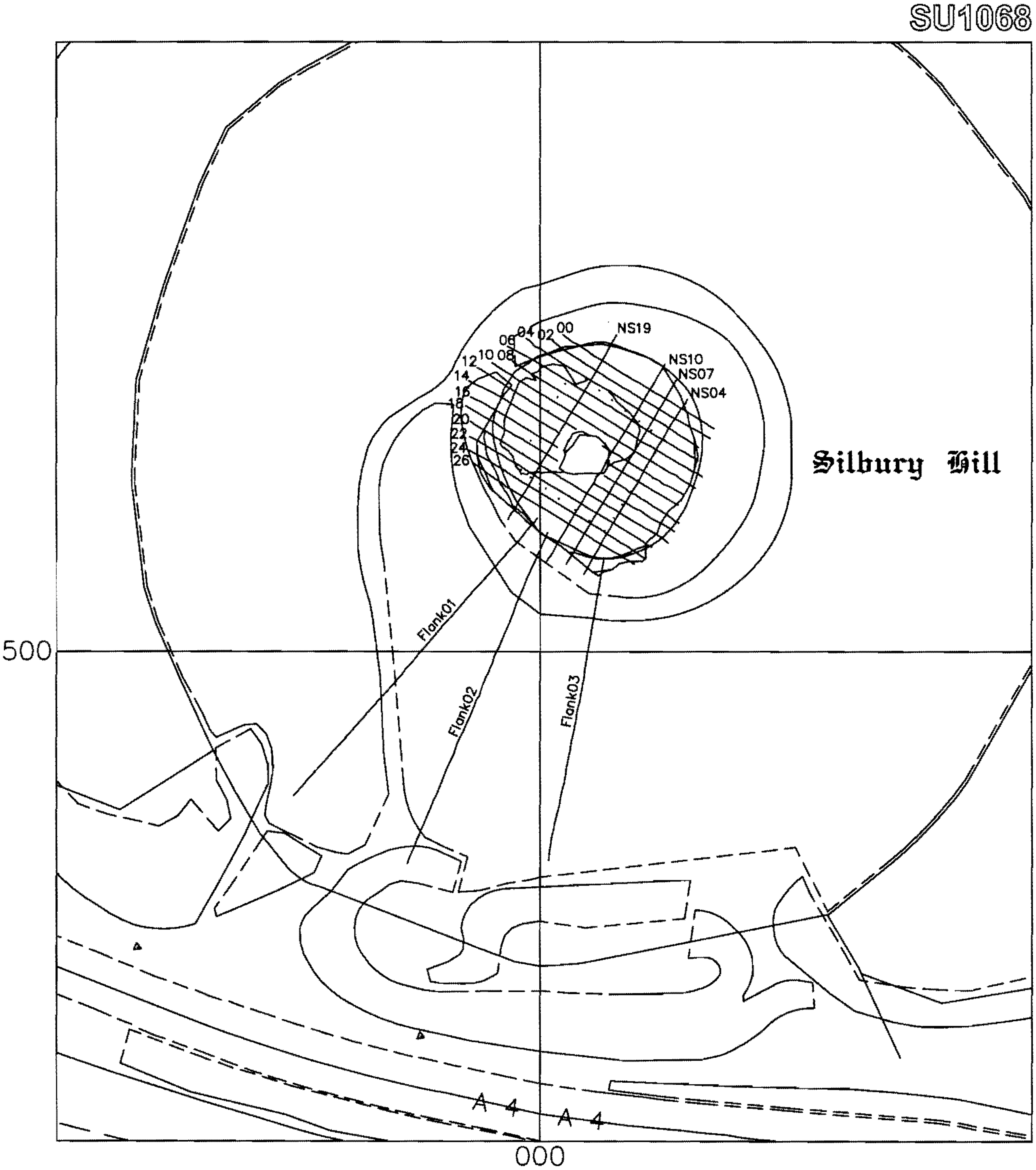
It is the opinion of the manufacturer of the Geoscan instrument that two sensors placed

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 electrical profiles, June 2001.



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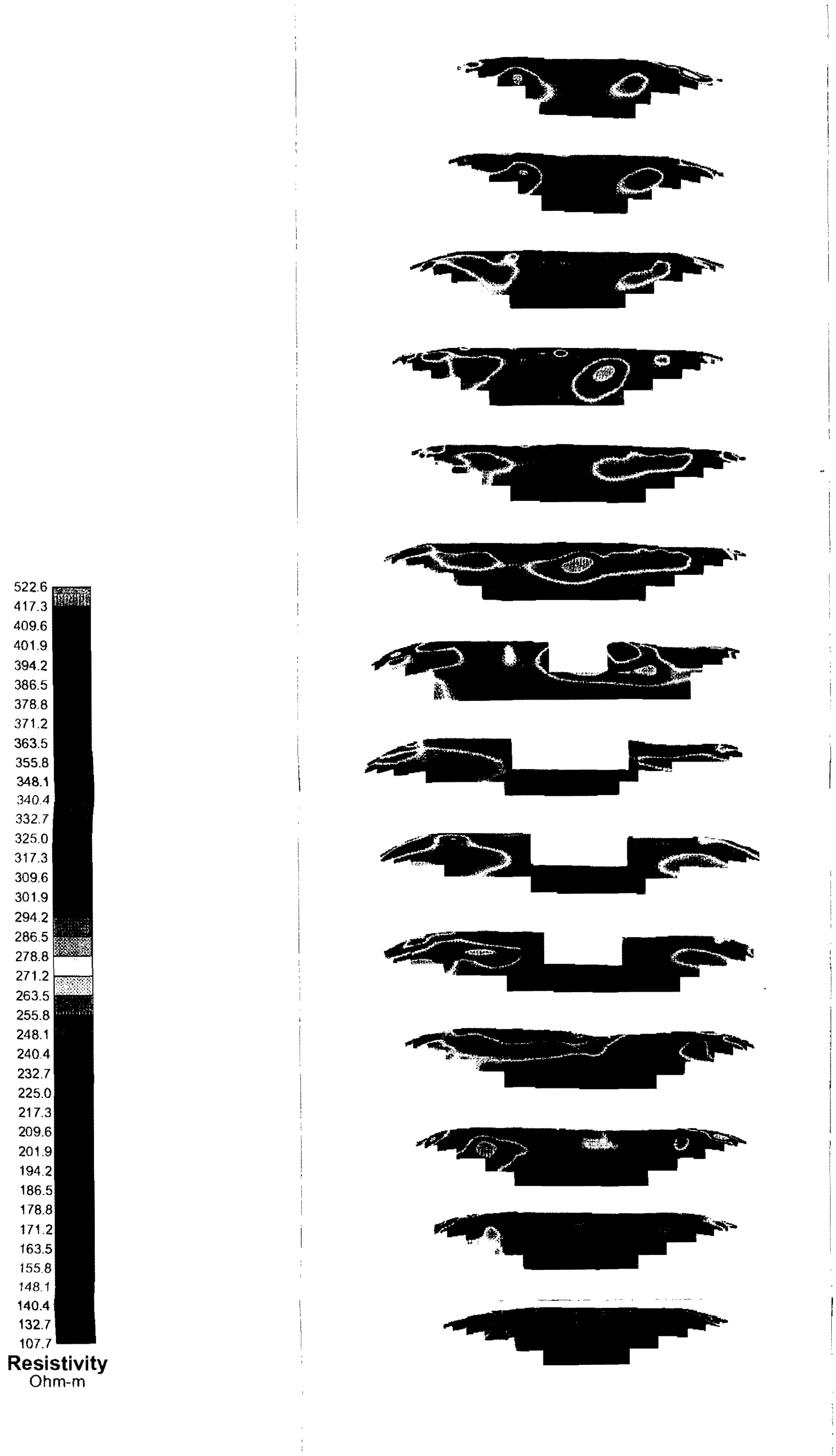
0 30m
1:1000

Centre for Archaeology, 2001



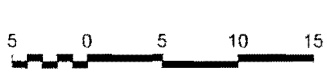


Figure 2) Silbury Hill, Wiltshire
East-West electrical profiles on top of hill

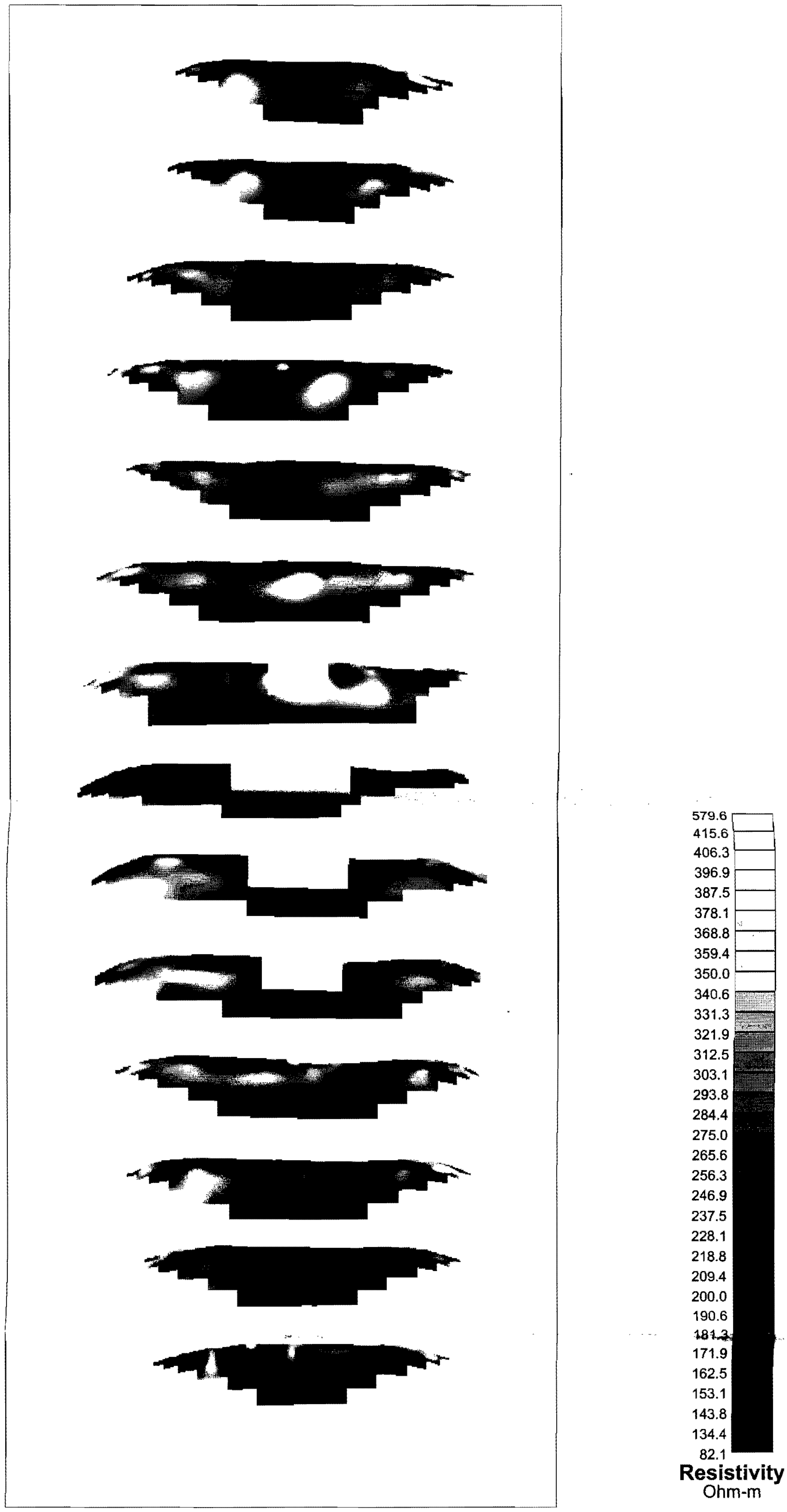
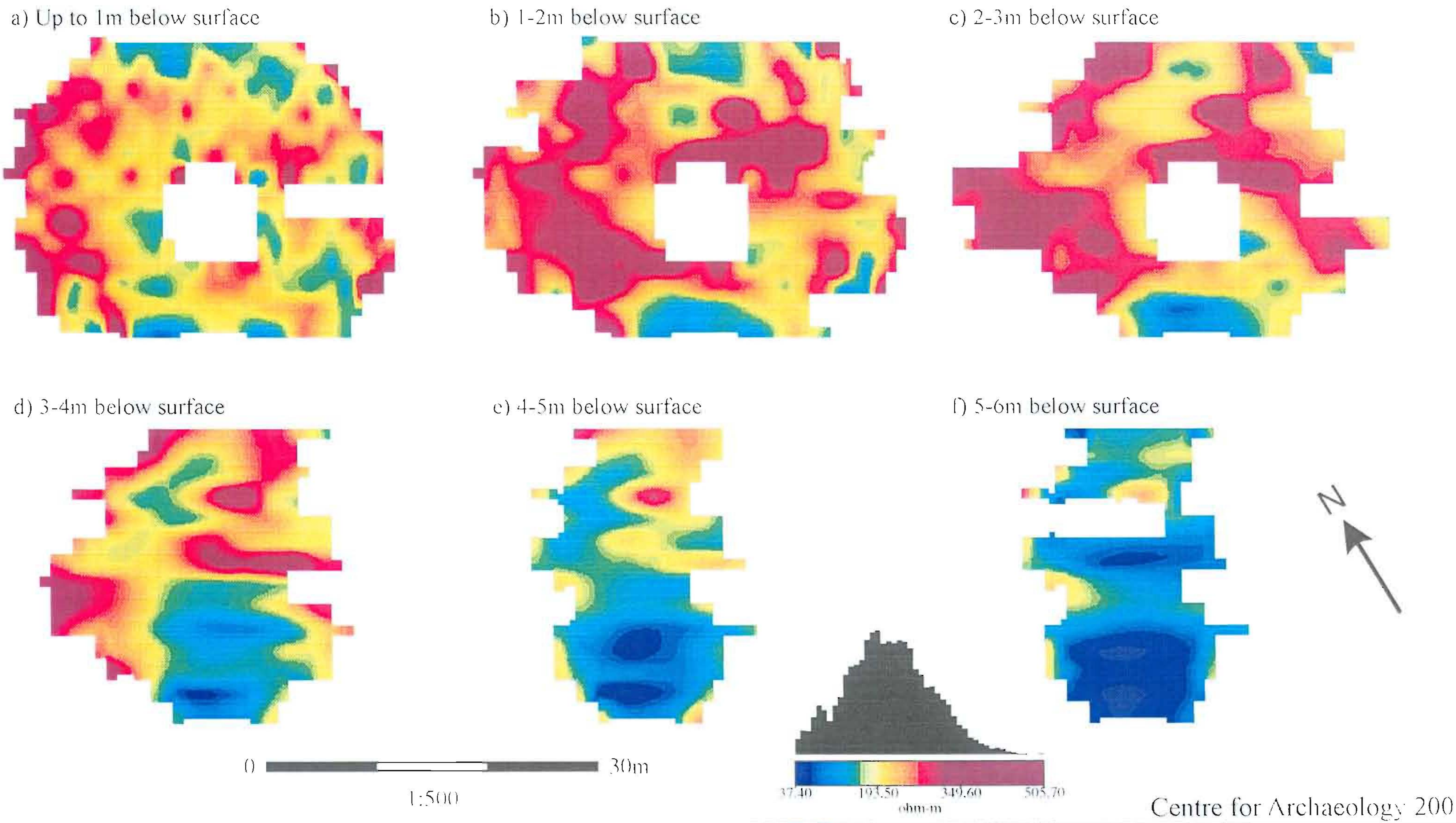
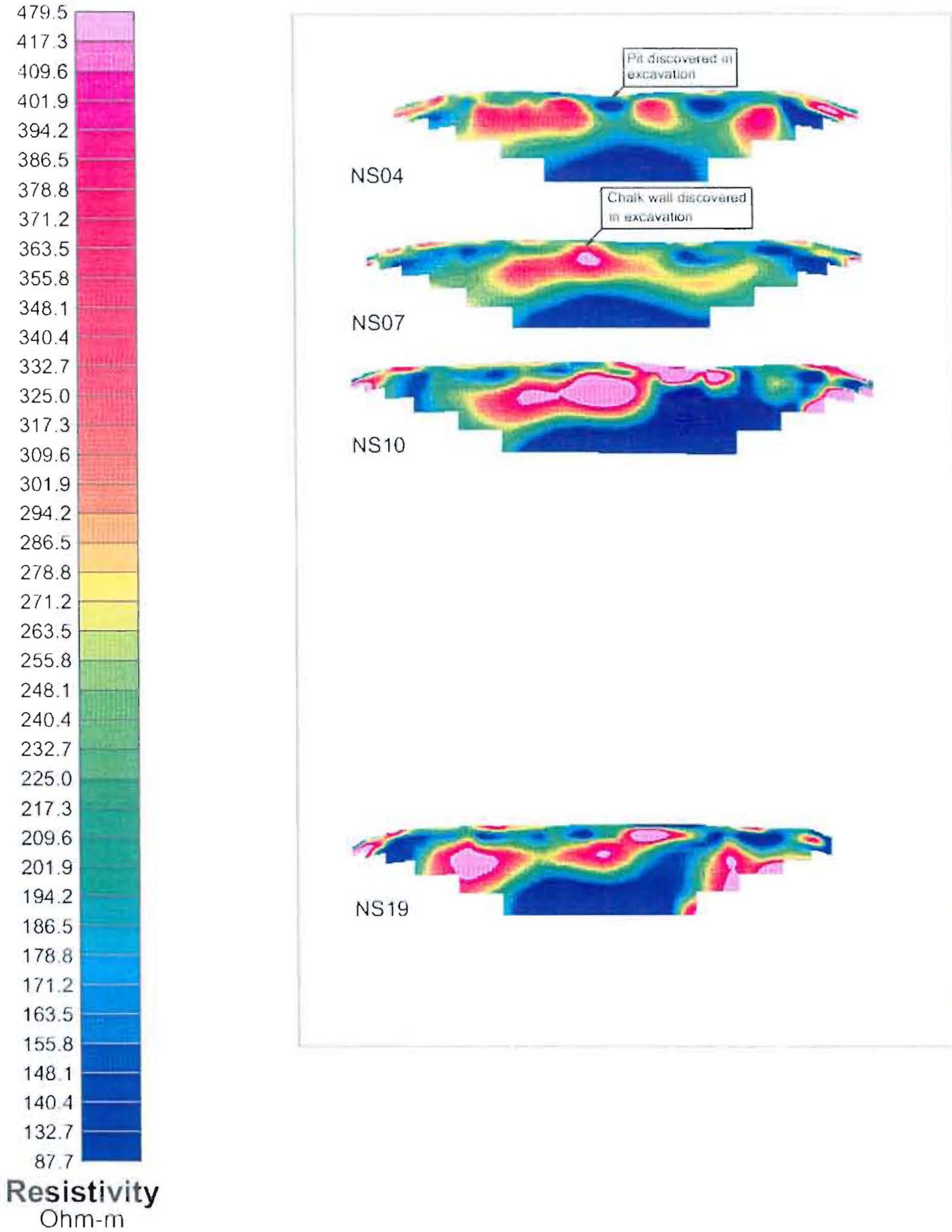


Figure 3) Silbury Hill, Wiltshire
East-West electrical profiles on top of hill

Figure 4) Silbury Hill, Wiltshire: Colour plot of horizontal sections through electrical profiles on top of the hill, June 2001.





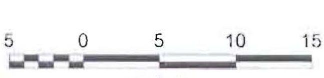


Figure 5) Silbury Hill, Wiltshire

North-South electrical profiles on top of hill

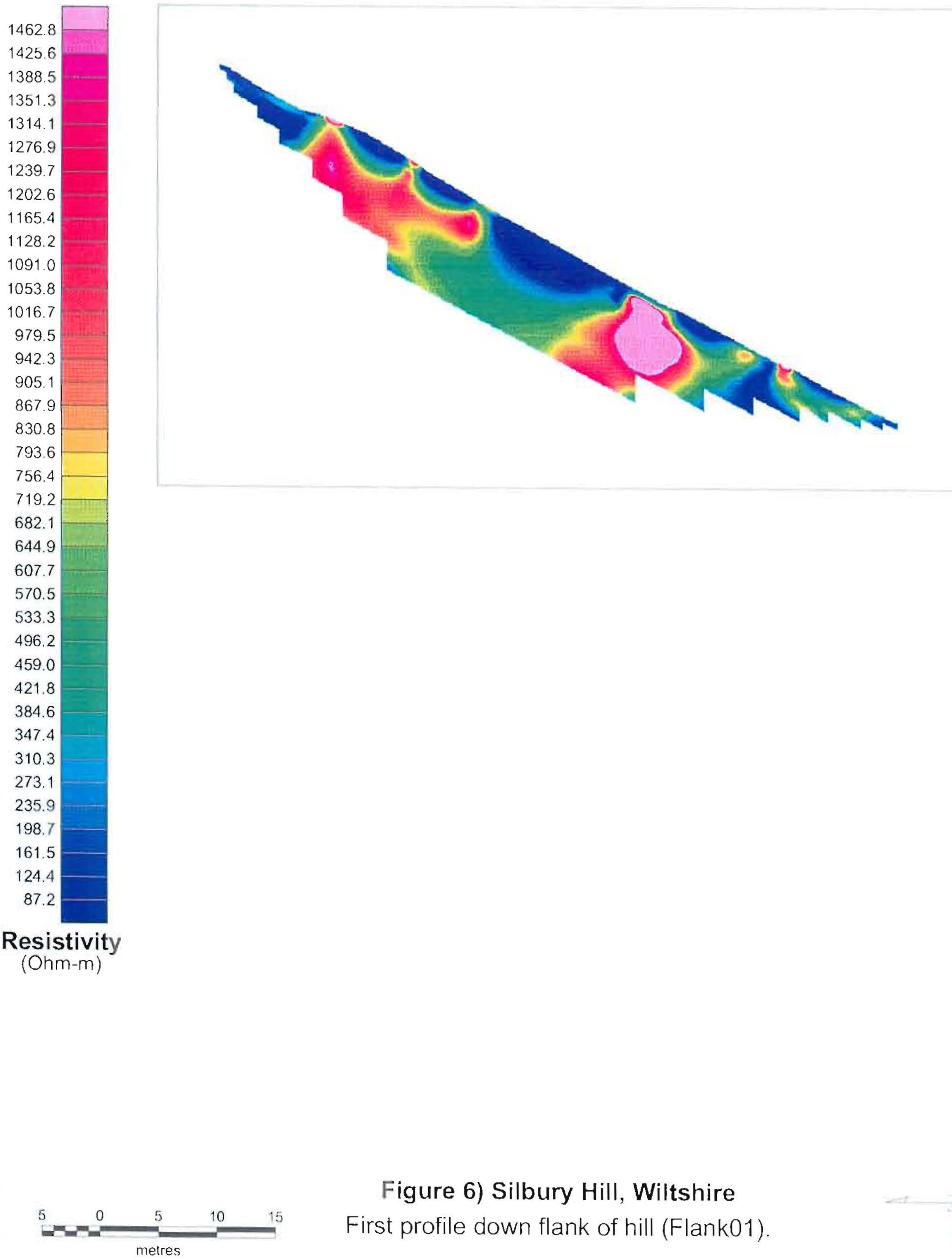


Figure 6) Silbury Hill, Wiltshire
First profile down flank of hill (Flank01).

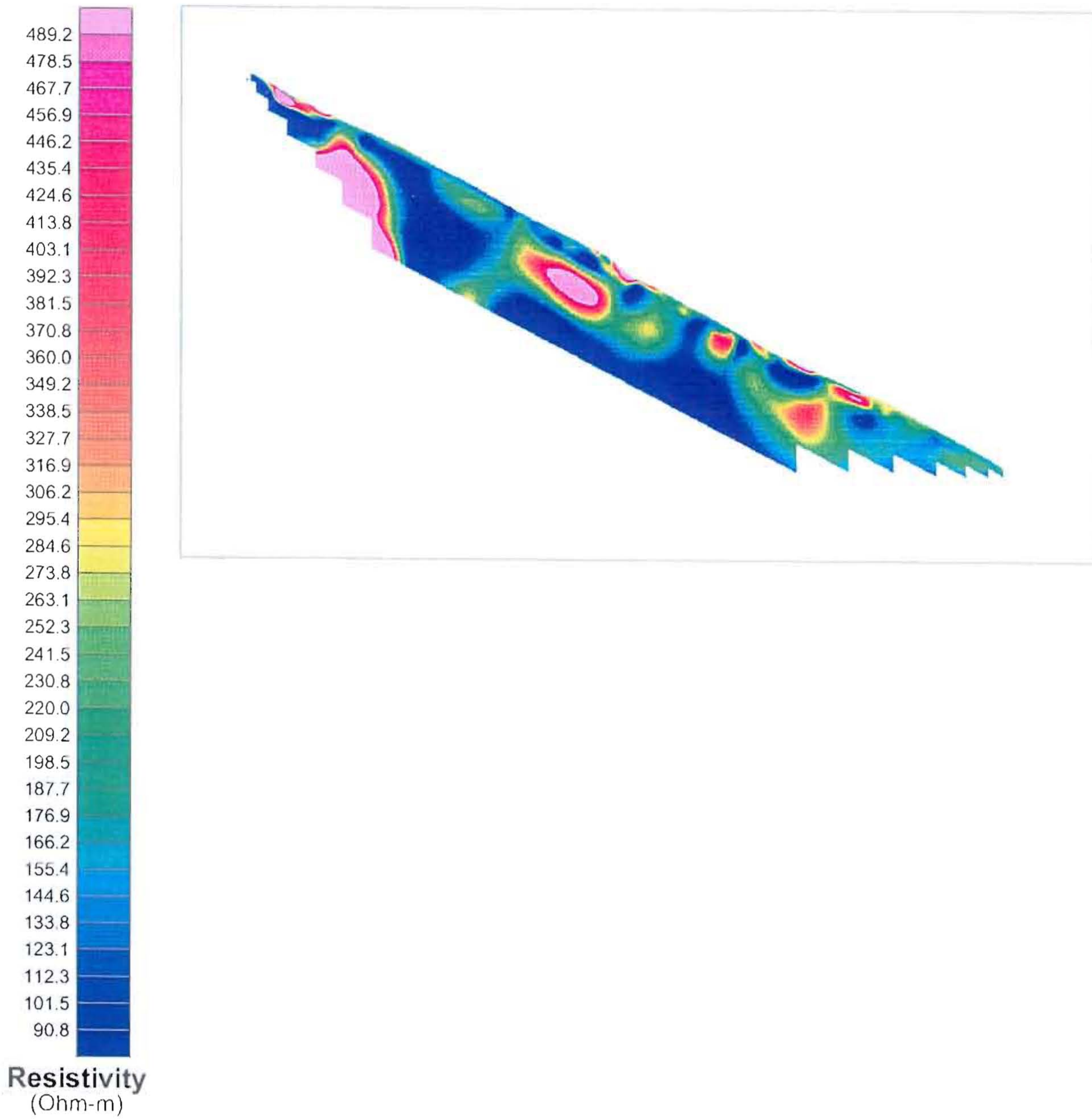


Figure 7) Silbury Hill, Wiltshire

Second profile down flank of hill (Flank02).

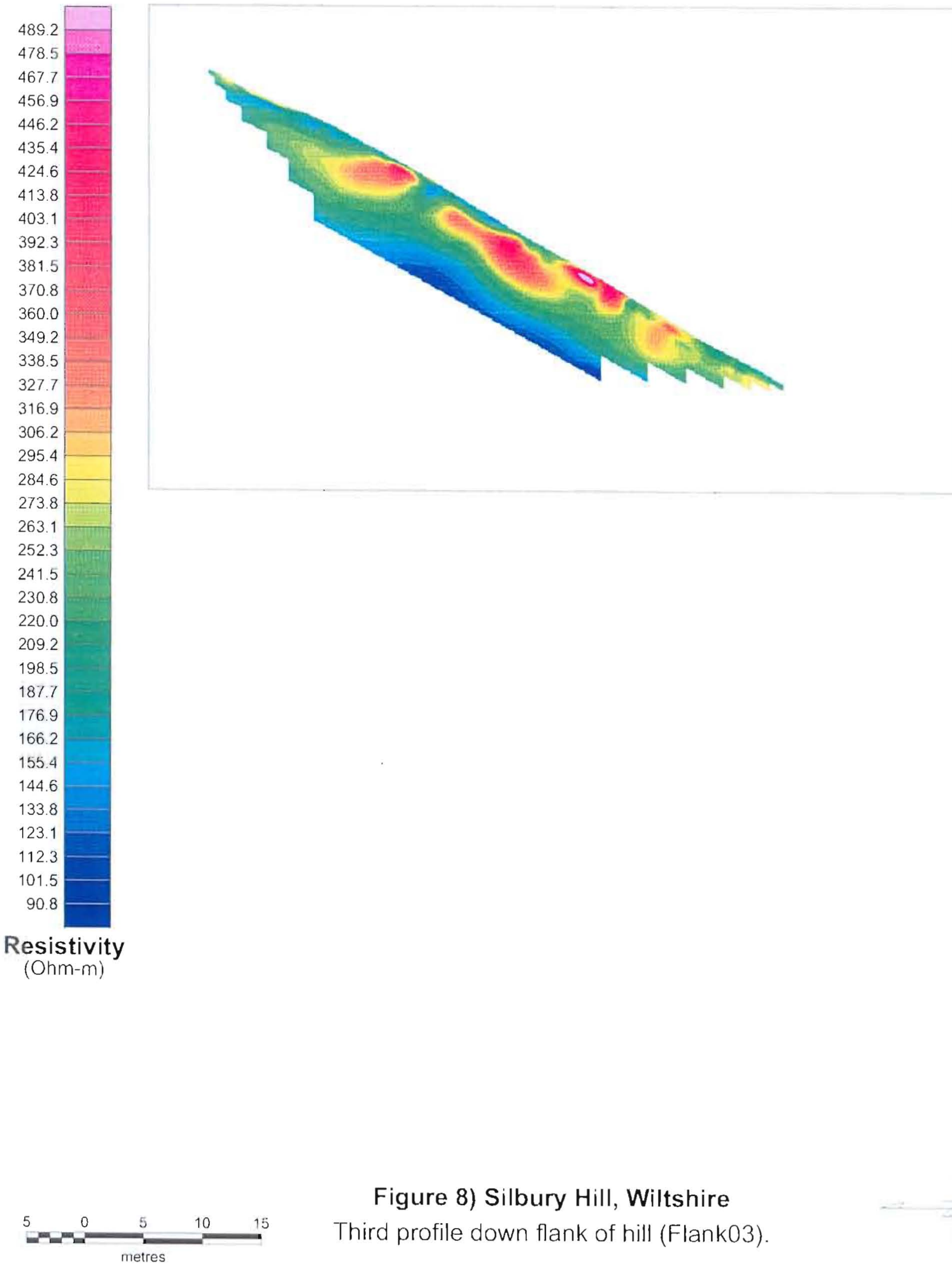


Figure 8) Silbury Hill, Wiltshire
Third profile down flank of hill (Flank03).

Figure 9) Silbury Hill, Wiltshire: Interpretation of electrical profiles on top of hill, June 2001.

Key

Possible compacted chalk wall.

High resistance anomaly.

Low resistance anomaly.

0 15m
1:500

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