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Geophysical Surveys within the Stonehenge Landscape: A Review of Past Endeavour and Future Potential

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Introduction

DESPITE ITS DILAPIDATION, the monumental durability of Stonehenge and its conspicuously planned disposition have perhaps inclined the minds of earlier antiquarians away from the search for less durable traces nearby. Of course the presence of earthen features such as the Avenue and the Great Cursus, and many lesser monuments, did not escape the very acute observations of Aubrey, Stukeley and their successors. However, it is perhaps the remarkable physical persistence of the more obvious monuments that has allowed these to absorb much initial archaeological enquiry, away from a wider and more penetrating search of the surrounding chalkland.

From early in the present century, however, the development of aerial reconnaissance has activated a more holistic appreciation of this landscape in which many subtle and denuded archaeological traces have manifested themselves when viewed from far above. For the future, aerial photography (and now airborne and satellite multi-spectral imagery) will continue to provide a rich source of information about the less tangible physical remains which complement the more upstanding and enduring earthworks so familiar on the ground surface.

From the 1940s it became apparent that there were other methods, aside from observation and excavation alone, which could be used to explore for archaeological features. These geophysical techniques, adapted and scaled down from their geological analogues, were soon shown to be able to locate buried features invisible from the surface. The historic first application of resistivity surveying clearly demonstrated this ability at a monument complex, contemporary with Stonehenge, at Dorchester-on-Thames, Oxfordshire (Clark 1996, 11–14). However, despite such demonstrable promise, these novel and developing methods do not appear to have ever been pursued with much enthusiasm at Britain's most famous prehistoric site. This may be explained, not only by the tentativeness of these first developments in the new technology, but also by the prior existence at Stonehenge of such a relatively well documented landscape of monuments, supplemented by a productive aerial photographic record. Perhaps such methods seemed unnecessary where the surface expressions of so much prehistoric activity already seemed clear enough, and where the thin mantle of soil discouraged belief that much else remained to be found.

R.J.C. Atkinson, excavator at Stonehenge as well as the pioneer of archaeological geophysics at Dorchester, made only very limited use of the latter methodology in his studies at the monument: following the proposal that the Station Stones might be remnants of a stone circle he used resistivity survey to search for settings elsewhere on its presumed circuit, but without success (Atkinson 1979, 79). He also resorted to bosing (thumping the ground and listening for variations in resonance), and probing, the judicious use of the latter being helpful in locating various features such as Aubrey Holes, Z and Y Holes and the stone-hole within the North Barrow (ibid. 32–4).

It was not until the late 1960s that more advanced techniques became available, especially fluxgate magnetometry, and with them the ability to routinely explore larger areas of ground. Such techniques were nevertheless used only sparingly, and not at all at Stonehenge, until 1979–80 when a portion of the Avenue was investigated by the Ancient Monuments Laboratory (Bartlett and David 1982). Then, following emphatic recommendations by the Royal Commission on Historical Monuments (RCHM(E) 1979, xv), several geophysical surveys were conducted in the environs of Stonehenge as part of a wider research and evaluation project (Richards 1990). It was in fact not until 1994–5, following further technical progress, that Stonehenge itself and its immediate vicinity was comprehensively geophysically surveyed (Payne 1994, 1995). This latter project was undertaken specifically to provide detailed geophysical information in support of the preparation of a full account of the twentieth-century excavations at Stonehenge (Cleal *et al.* 1995).

In fact, after so much apparent neglect in the history of its investigation the Stonehenge area has lately seen an unprecedented amount of geophysical survey activity. This has partly been linked to those research and post-excavation initiatives referred to above, but a very substantial contribution has been made as a direct consequence of development pressures within the World Heritage Site. Both the need to locate a new visitor centre, and to upgrade the existing road network, have necessitated extensive evaluation of the archaeological potential of the areas affected by these plans. Several options for siting the developments have had to be considered, and each assessed by geophysical methods, leading to a vast survey coverage (see Fig. 1). The pattern of this coverage has of course been dictated by many practical considerations, one of which has been a concern to avoid sites of obvious archaeological importance. Whilst the opportunity to undertake such survey is very welcome, and in places coincides with locations of considerable archaeological significance, it must be recognised that it is nonetheless driven by an agenda quite detached from archaeological research.

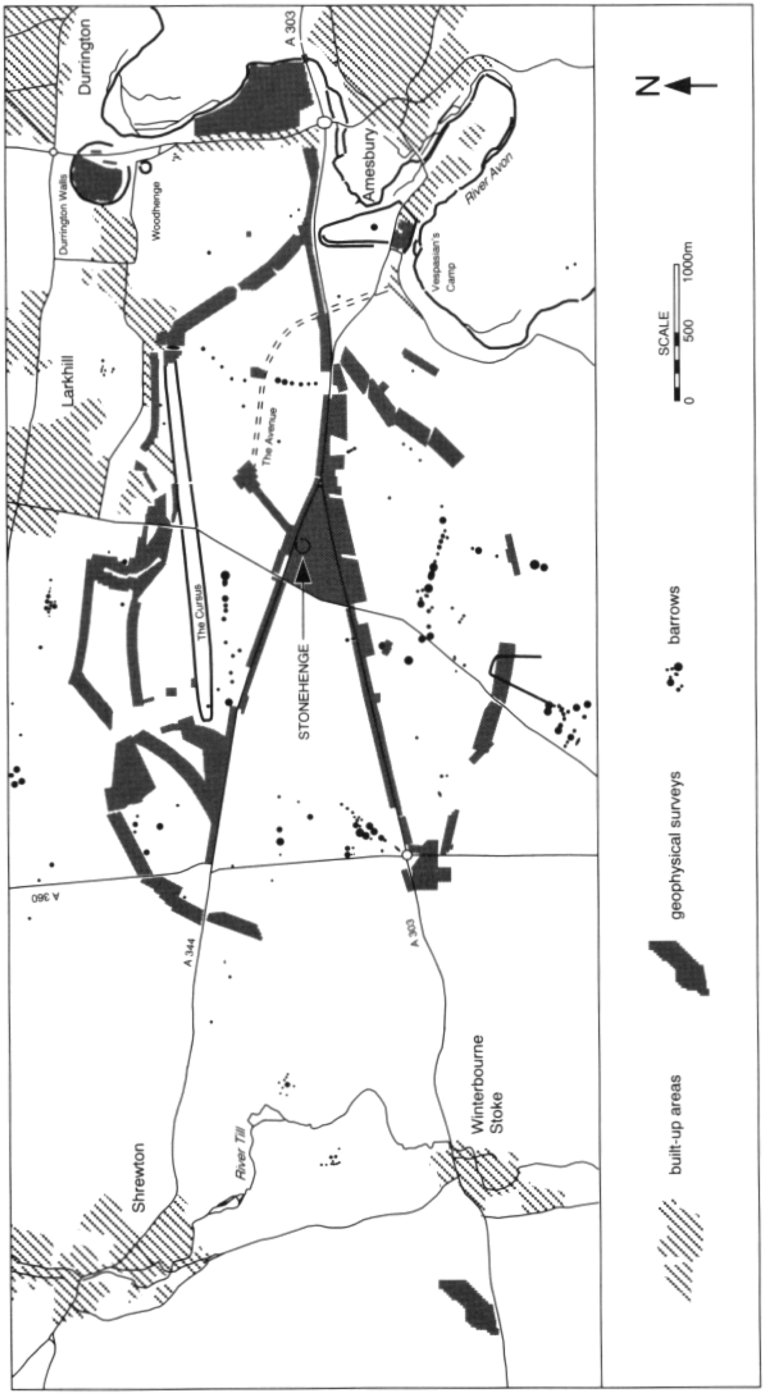


Figure 1. The distribution of geophysical survey, almost all of it fluxgate gradiometer survey, in the Stonehenge area.

It is our purpose in the remainder of this paper to review the results of the totality of geophysical survey that has taken place within the World Heritage Site, some 183 hectares, concentrating especially upon the work undertaken since 1990. We will conclude by discussing how the current and developing geophysical technologies might be able to address outstanding archaeological issues at Stonehenge, and will propose specific areas and sites where such endeavours might be most appropriately targeted. Firstly, however, it is necessary briefly to summarise the main techniques of archaeological geophysics that are, and will be, relevant to such a programme.

Geophysical survey methods

The details of the principles and methodologies of archaeological geophysics are by now very well rehearsed in the literature and need not be repeated here (see for instance, Aitken 1974; Tite 1972; Clark 1996; Scollar *et al.* 1990). The methods which have seen greatest employment at Stonehenge are those which already have an established role in the discipline: resistivity and magnetometry, supplemented occasionally by geochemical survey (phosphate and magnetic susceptibility), probing and augering.

Magnetometry involves the measurement of the local magnetic field strength at close intervals (1.0 m or less) across the ground surface. The magnetometer (usually a fluxgate gradiometer) responds to perturbations in the local magnetic field caused by localised concentrations of soil, magnetically enhanced particularly by burning, that infill buried features such as pits, ditches and the larger post-holes. It also detects the remanent magnetisation of hearths and industrial features such as kilns and furnaces. These remains are revealed as patterns of magnetic anomalies visible in computer-generated plots of the areas surveyed.

Resistivity survey, where an electrical current is introduced into the soil and the (apparent) resistance to its passage is measured, responds to variations in porosity and moisture content—variations which can in turn relate to buried archaeological features. This method is often selected when the presence of building foundations is suspected, but is also well capable of detecting large stones, pits, ditches and other features when the prevailing moisture conditions allow. As with magnetometry, the outcome of resistivity survey is a two-dimensional spatial plot of the area surveyed. The depth of detection is related to probe spacing which is often set at 0.5 m, giving a detection depth of some 0.75 m. Current research is aimed at investigating the potential of multiprobe arrays for the reconstruction of resistivity variation with depth (Aspinall 1992; Szymanski and Tsourlos 1993).

Aside from resistivity and magnetometry, electromagnetic methods (EM) of detection have seen much more limited use at Stonehenge, but are likely to have a continuing role in the future. These methods include the (continuous wave) measurement of soil conductivity, soil magnetic susceptibility (MS) and ground penetrating (impulse) radar (GPR).

Soil conductivity survey provides results which are directly comparable with those of resistivity survey but without the necessity for the repeated insertion of electrodes.

Variation in soil magnetic susceptibility is the key to magnetic detection. Topsoil contains a proportion of magnetic iron oxides inherited from the parent material and when these are subjected to burning, as on a settlement or industrial site, they become magnetically enhanced. If this enhanced material, with a relatively high magnetic susceptibility, becomes concentrated within cut archaeological features, such as pits, it can generate a corresponding and detectable magnetic anomaly.

More subtly, the effect of artificially enhanced magnetic susceptibility can be retained in the topsoil alone, whether or not archaeological features survive beneath it. Thus, measurement of topsoil MS (at intervals of, say, 10 m) over a large area (up to many hectares) can, by isolating zones of higher readings, suggest the former presence of settlement or industrial activity. Such a generalisation is not without its problems, however: the mechanisms of magnetic enhancement, apart from burning, are still only imperfectly understood; nor is it yet possible to counteract fully the effects of natural variations in MS, or the effect of modern influences. Whilst MS survey can thus be used as a prospecting technique in its own right, and can be a valuable approach to preliminary site reconnaissance, its results must be interpreted with caution, and preferably in accompaniment with indications provided by magnetometry and/or other survey methods (English Heritage 1995). MS surveys have been made at several locations in the Stonehenge area as a supplement to magnetometer survey.

Despite much recent publicity, the role of ground penetrating radar in British archaeology is not yet well established. Although the technique is suited to the detection of voids and the structural features of building fabric, it has generally been much less successful in the discrimination of archaeological features from amongst their surroundings. The effectiveness of the technique is hindered by moist and clay-rich soils and, whilst capable of detecting major dielectric interfaces, has not demonstrated that it can unravel the more complex and subtle nature of much archaeological stratigraphy. One of the very first occasions on which it was applied archaeologically was at Woodhenge in 1981 (Clark 1996, fig. 91) and, on the same occasion, at Durrington Walls. Transects across both ditches only partially detected their profiles and revealed no stratigraphic detail. Despite this apparent lack of promise, GPR may have a future role in the Stonehenge area and this is referred to again below.

Thus, despite some very tentative experiments with GPR and other EM methods, much of the geophysical prospecting that has taken place around and within Stonehenge has been undertaken with magnetometry and, to a much lesser extent, resistivity. Although these techniques have now been in use for several decades they remain immensely effective. Recent years have seen the development of sophisticated archaeologically dedicated instruments and these, helped by advances in computing, have allowed great improvements in the speed and presentation of these types of survey.

In the next section we will briefly review the results of previous work in more detail.

This is perhaps best achieved by taking first of all the studies of the major individual monuments, before moving out to surveys undertaken more widely within their surroundings.

The monuments

The Stonehenge enclosure and stone circles

The reasons for an apparent reluctance to embark on a survey of the henge itself have already been referred to at the beginning of this paper. Apart from the success of probing, demonstrated by Atkinson, little or no geophysical investigation appeared to be warranted in subsequent years. A trial magnetometer survey by the Ancient Monuments Laboratory (AML) in 1988, just outside the henge ditch, did nothing to dispel a general impression that this method, at least, would not be very revealing. However, this impression was eventually set aside and in 1994–5 a full magnetic and resistivity survey was undertaken. Whilst magnetometer survey might be of limited value because of excessive magnetic interference resulting from twentieth-century activity at the site, there was some confidence that resistivity might be more productive. Recently, the latter had certainly proved able to locate the positions of former stone settings within the Avebury henge and along the line of the West Kennett Avenue (Ucko *et al.* 1990).

The methodology and results of the AML survey have been described and illustrated in detail by Payne (1994, 1995) and only the most salient points should bear repetition here. Magnetometer readings were taken at 0.25 m intervals along traverses spaced 1.0 m apart. Instrument sensitivity (using a Geoscan FM36 fluxgate gradiometer) was set at 0.1 nanotesla (nT). The resulting magnetometer plot, as predicted, is massively interrupted by extreme responses to ferrous litter and clinker in the soil, underground cabling, metal underpinning, former fence lines and trackways. Of the prehistoric features, the enclosure ditch has been detected throughout its circuit, but without sufficient clarity to determine its detailed morphology. Within the ditch circuit, many of the excavated Aubrey Holes have been detected on account of ferrous material in their twentieth-century backfilling. Similarly the backfillings of stone-holes D and E and the hole for stone 92 (one of the Station Stones) have been detected. Up to 15 unexcavated Aubrey Holes have been located, their weakly defined positive magnetic anomalies corresponding with both localised low resistivity (see below) and the much earlier results of probing. Less clearly, it is possible that the magnetometer has picked up a number of Y Holes (Fig. 2).

Resistivity readings were obtained over the same area using a Geoscan RM15 meter. The Twin Electrode configuration was used with a mobile probe spacing of 0.5 m and a reading interval of 0.5 m. The resulting data are illustrated in Figure 3 in the form of a greytone plot which has been numerically enhanced (using a 3m Gaussian high pass filter) to clarify significant anomalies. Figure 4 illustrates the same plot overlain by the outlines of the excavated portions of the site, and with significant resistivity anomalies indicated by letters.

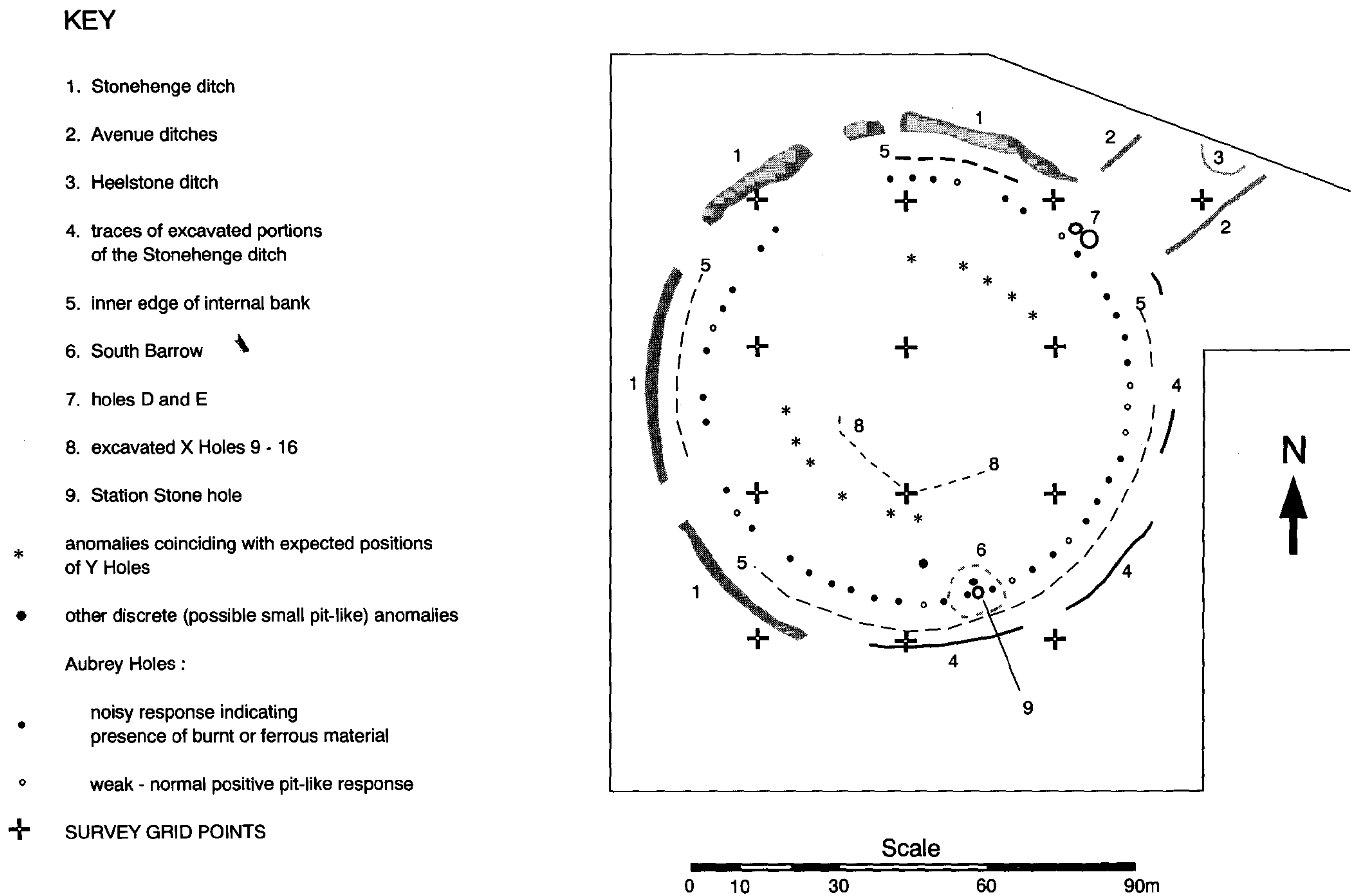


Figure 2. Features located by magnetometer survey within the Stonehenge enclosure.

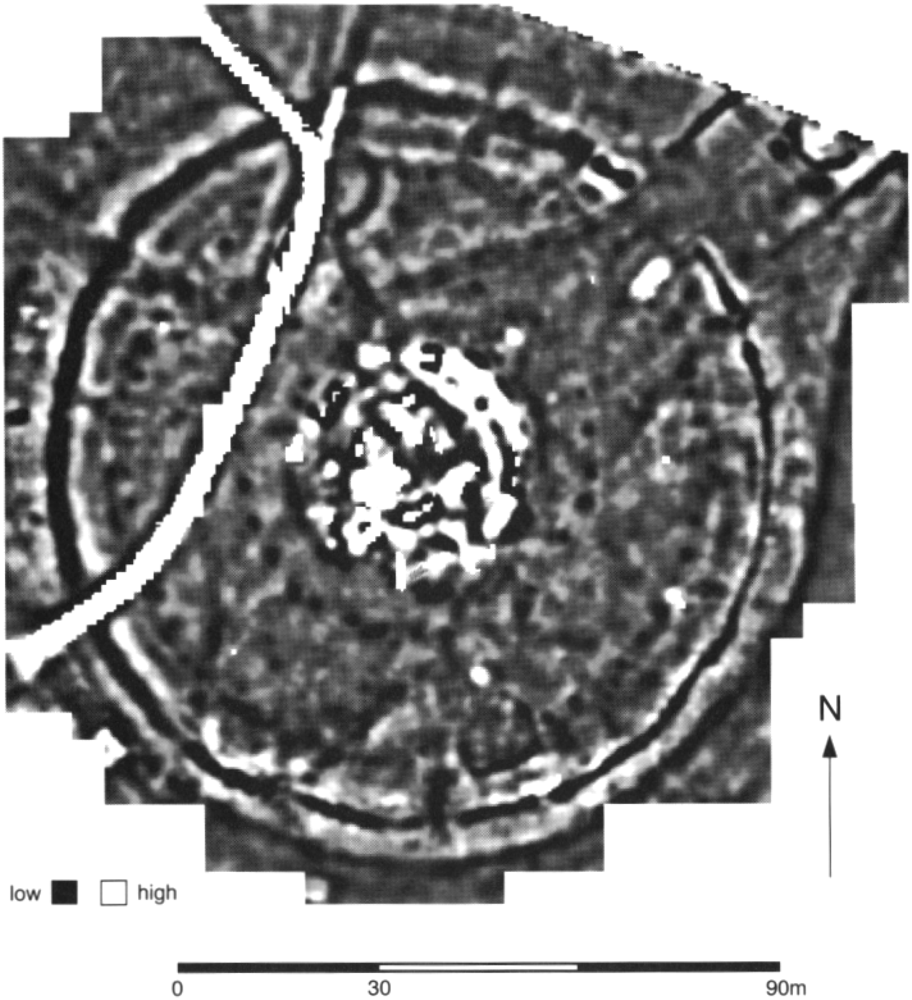


Figure 3. Greytone plot of the resistivity survey of the Stonehenge enclosure (3m Gaussian high pass filter).

As with the magnetometer survey, the resistivity results also reflect the recent history of the site—but to a somewhat lesser degree. The low resistance henge ditch is clear, as is the bank within it, defined by a zone of higher readings. More surprisingly, the survey demonstrates that there is also a bank of similar dimensions on the outer side of the ditch. Although a modest counterscarp bank is visible as a slight topographic feature in places, the resistivity data illustrate for the first time that this is the remnant of a once much more substantial and continuous feature. The data suggest that the morphology of the ditch itself, in plan, is a little irregular in places and slightly raised readings here and

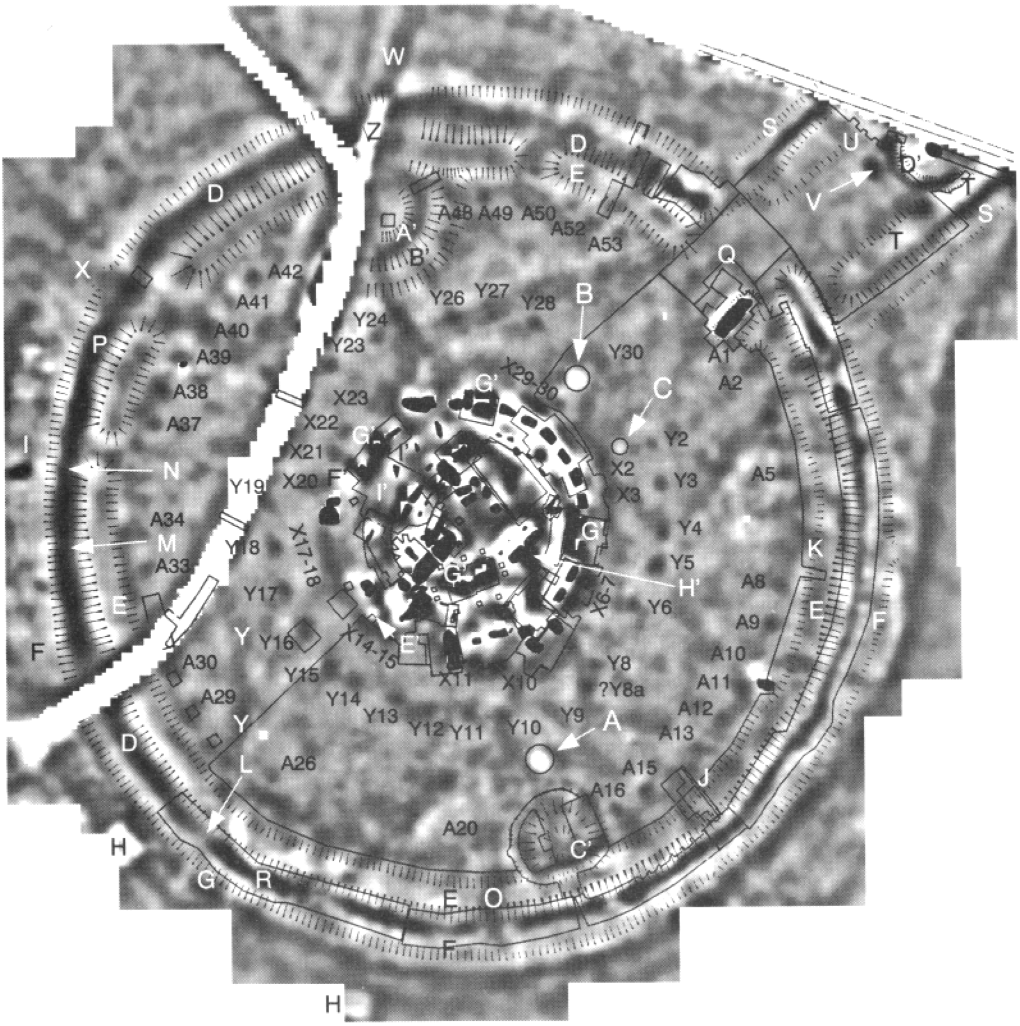


Figure 4. An interpretation of the resistivity survey of the Stonehenge enclosure.

there hint at the presence of segmentation. The purported southern entrance causeway has not been clearly detected, due to the influence of Hawley's excavation there, but its existence is confirmed by the faint detection of a corresponding break in the two banks (O on Fig. 4).

Within the henge, up to 28 out of the 56 Aubrey Holes have been detected as very weak anomalies, 13 of them unexcavated. Many would probably not have been recognised were their existence not already known from probing. This rather disappointing result must be accounted for by their small size and the poor moisture contrast offered by their fillings. However, the fillings of the Y and Z Holes are more uniform and fine-textured than those of the Aubrey Holes, and have been detected more emphatically. Some 23 Y Holes and 16 Z Holes, inclusive of both excavated and unexcavated examples, have been found, as have the ditches of the North and South barrows.

Three isolated high resistance anomalies (A, B and C on Fig. 4) have aroused some interest as they could perhaps represent buried stones or stone settings. However, they lie in areas that have apparently been excavated (Cleal *et al.* 1995), and must remain unexplained since no corresponding features have been reported. Amongst the stone circles themselves, the highly complex and interrupted nature of the subsurface has defeated the ability of the survey data to discriminate much useful detail (Payne 1995, fig. 263). The only unexpected result was the location of a previously unidentified excavation trench sited immediately to the south-east of trilithon stone 52. This interpretation seems to be confirmed by the results of augering undertaken by Wessex Archaeology (Allen and Gardiner 1994).

The Avenue

Parts of the Avenue have been targeted by geophysical survey on several occasions, and its Stonehenge terminal was included within the resistivity and magnetometer coverage described above. The ditches here were detected by both methods, and resistivity also picked up the bank on the inside of the southern ditch (its counterpart having been eroded by a later cart-track). The Heelstone Ditch was also detected by both methods, and resistivity appears to have picked up the position of the previously excavated stone-hole B.

Survey coverage along the line of the Avenue is now nearly continuous for some 700 m north of its Stonehenge terminal, extending well beyond its angular deflection in Stonehenge Bottom. This coverage is an amalgam of separate surveys, all undertaken by the AML at different times over a period of 11 years (Payne 1995, 506–10). In addition, minor magnetometer surveys have located the Avenue further eastwards along its course at King Barrow Ridge (Bartlett 1990; Richards 1990, 112–13) and just to the north of its intersection with the A303 road (Bartlett 1994).

The earlier surveys, along the straight section of the Avenue north-east of the henge, were motivated by the persistent contention, originated by John Aubrey in 1666 and reasserted by Stukeley and his friend Roger Gale, that there were once twin rows of stones lining the Avenue (Bartlett and David 1982, 90–3). No surface indications now survive, however, and unfortunately neither this nor any subsequent geophysical survey has been able to resolve this problem conclusively. Poorly defined magnetic and resistivity anomalies have been found at a variety of locations in and around the Avenue but no pattern is evident and their significance remains unknown (Payne 1995).[1]

1. Since this paper was prepared a very detailed caesium magnetometer survey has been undertaken over part of the Avenue north of the A344, in May 1996, in the hope—perhaps—of resolving whether or not former stone settings can be detected here. The survey was undertaken by Dr Jörg Faßbinder in association with the AML and the results are to be compared against a new set of detailed fluxgate magnetometer measurements.

Another contention which has its origins amongst antiquarian observations (e.g. Stukeley 1740, Tab XXVIII) is that there may or may not have been a bifurcation of the Avenue at Stonehenge Bottom, with a now invisible branch leading away northwards towards the Cursus. Whether or not this was the case, the turn in the Avenue presents an obvious locus for investigation should there be any clues there as to why such a deflection was introduced into the overall scheme. Unfortunately, the magnetometer plots (Fig. 5) do not provide any such clues, although they demonstrate conclusively that the Avenue does not divide at this point.

Other features in the near vicinity of Stonehenge

As part of the most recent campaign by the AML, the entire triangle of land containing Stonehenge, bounded to the north and south by the A344 and A303, and to the west by the farm track across Stonehenge Down, was surveyed with magnetometers (Fig. 6). This is an area of some 14.4 hectares and represents a substantial part of the core area of the World Heritage Site. The only visible surface remains, excepting Stonehenge itself, are barrows. Apart from the bell barrow (Amesbury 11) adjacent to the A344, there is a scatter of degraded barrows in the western part of the area, on Stonehenge Down, the majority of which are recorded as of simple bowl form (Grinsell 1957).

A glance at Figure 6 graphically illustrates the extent of magnetic interference accumulated from generations of modern activity around the monument, belied by a now comparatively unblemished isolation beneath pasture. This magnetic 'noise' around the stones themselves, along former tracks, fences and roads, and over the sites of former custodians' cottages and airfield buildings, may well mask the response from weaker and more significant magnetic features in some areas. Some of the modern anomalies may not be without interest themselves, however. For instance, the three large and strong (ferrous) anomalies isolated 100 m south of the centre of Stonehenge (Fig. 6) are unexplained. They do not appear to mark the location of huts used by Hawley's field team, nor that of 'Hawley's Graves', which were placed nearer the monument (Cleal *et al.* 1995, 18–19, fig. 11).

If the scatter of ferrous interference in the Stonehenge Triangle is ignored it may be suggested that most of this area is nearly devoid of obvious unsuspected prehistoric features. The survey has certainly located the ditches of each of the barrows and, for those on Stonehenge Down, has greatly clarified their outlines (Fig. 7). The latter are remarkable for their variety and it is notable that the smaller ring ditches (Amesbury 6–9) are incomplete, even 'hengiform' in outline. Most of these barrows were dug into by Colt Hoare in the early nineteenth century. He was unable to locate anything at Amesbury 10a, however, nor is there any magnetic indication that this 'barrow' is a genuine feature. On the other side of Stonehenge, an extremely weak and intermittent curving linear magnetic anomaly, some 60 m long, has been traced to the east of Amesbury 11 and *may* be a ditch. Elsewhere in the Triangle there are isolated instances where discrete anomalies

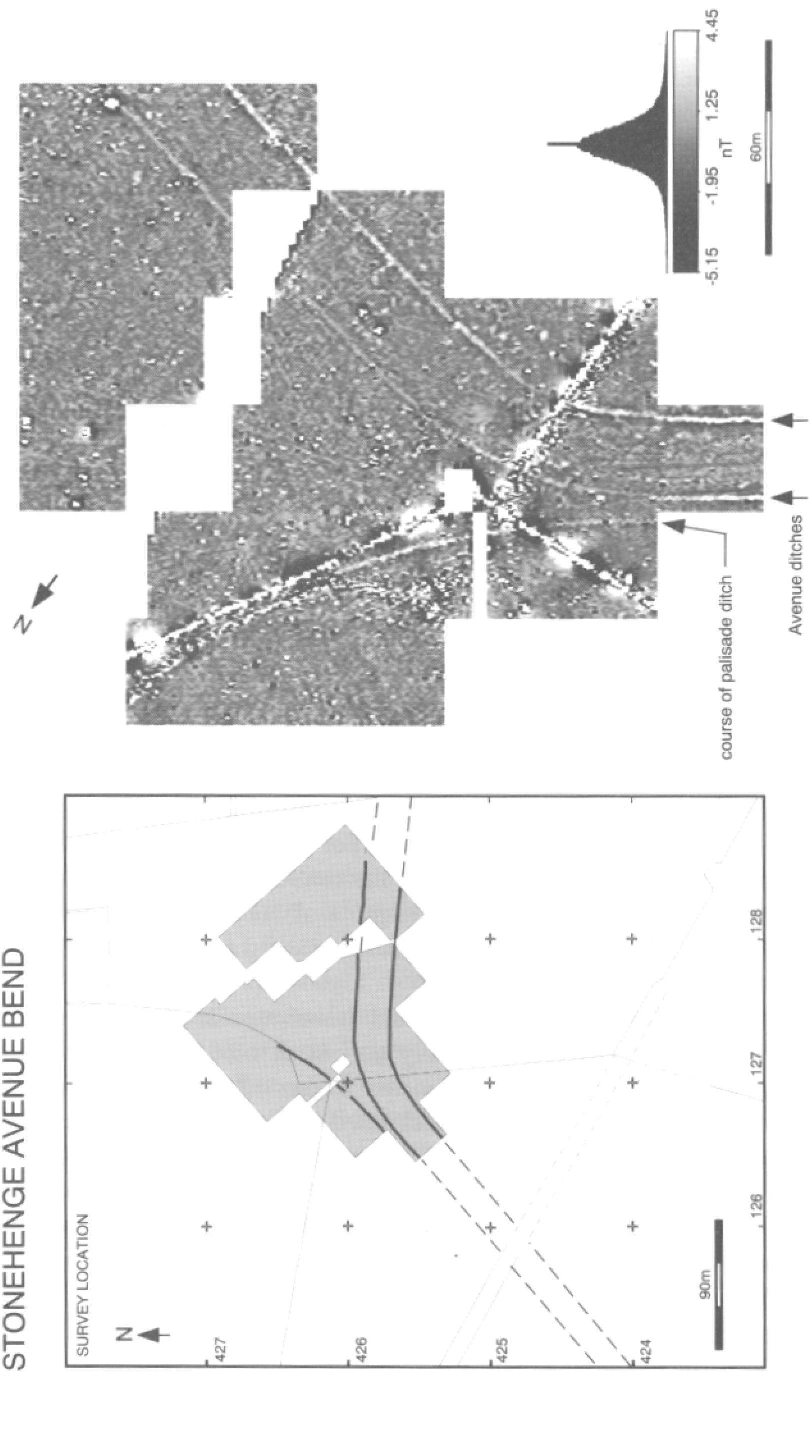


Figure 5. Greytone plot of the 1990 magnetometer survey of the bend in the Avenue. Note that, despite magnetic interference from pipes and fences, the course of the Palisade Ditch has been detected clearly.

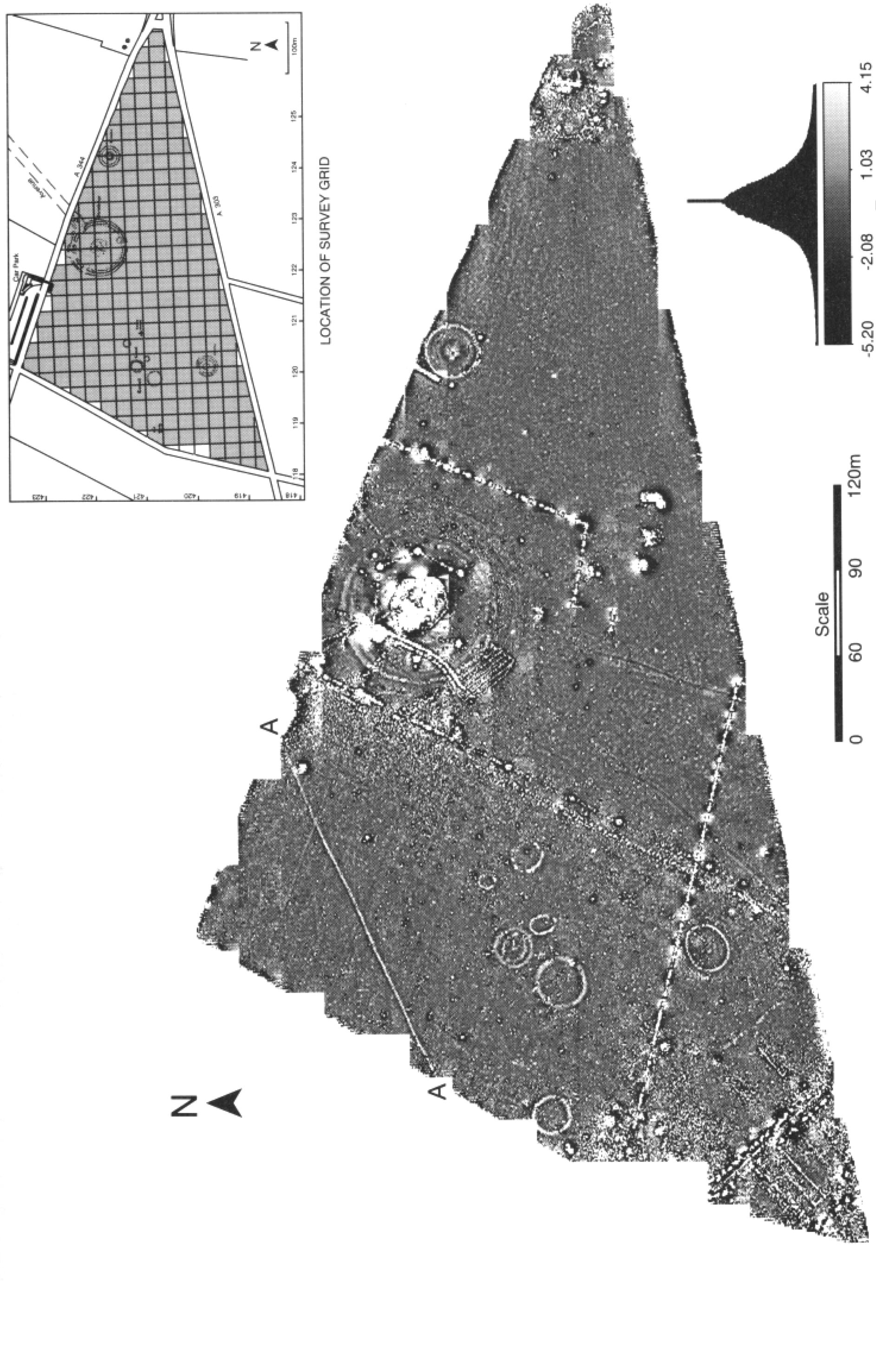


Figure 6. Greytone plot (much reduced) of the entire magnetometer survey of the Stonehenge 'Triangle'.

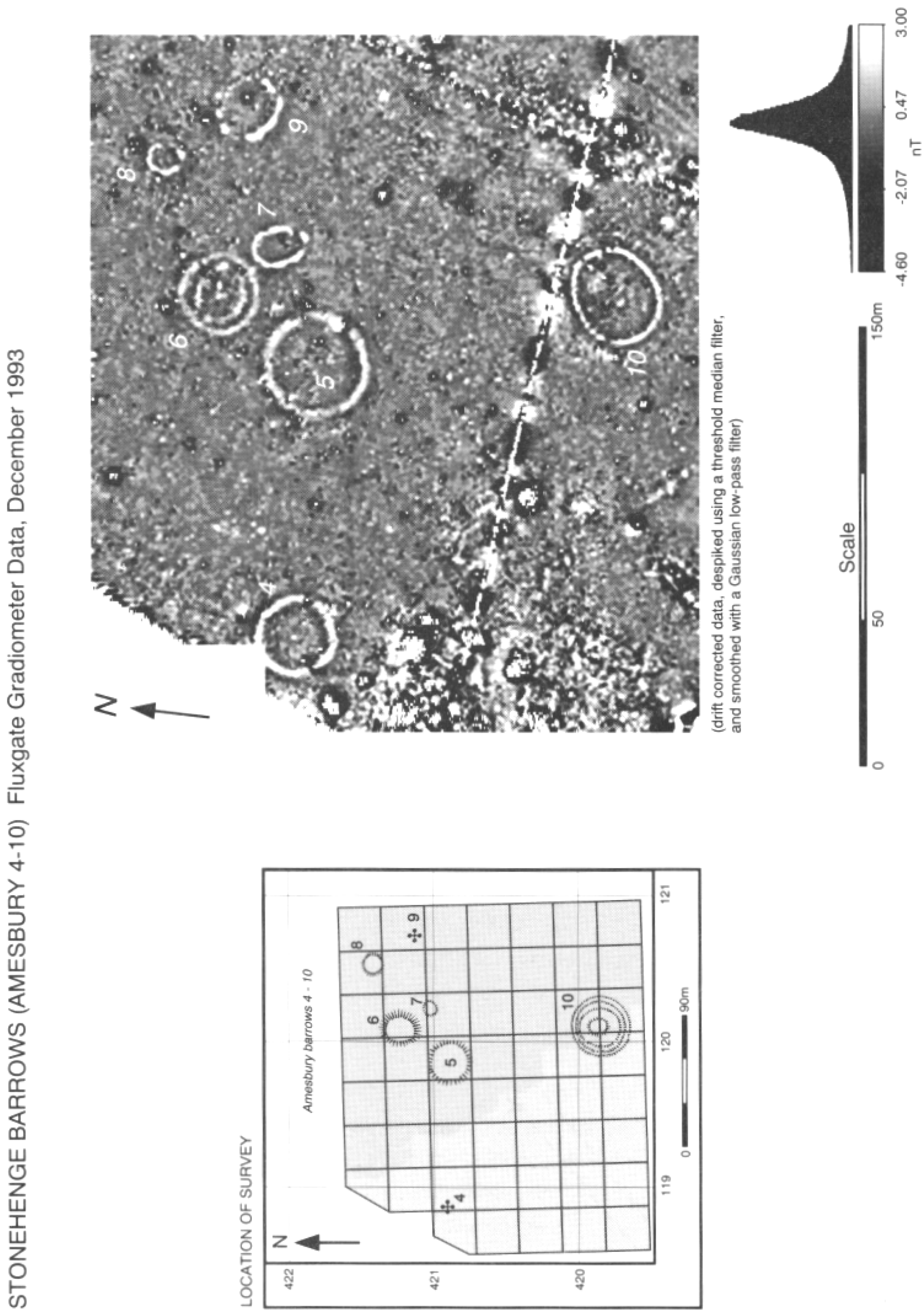


Figure 7. Detailed view of part of Figure 6, illustrating the detection of barrow features on Stonehenge Down.

could represent pits (some of which are 2 m or more in diameter), although nowhere are these unequivocal or concentrated in clusters suggestive of any particular focus of activity (Payne 1995, figs 8–11).

The Palisade Ditch

This ditch, passing to the north-west of Stonehenge and extending in a NE-SW direction for over a kilometre, was formerly thought to have been of Late Bronze Age date. Although still undated it has recently been reinterpreted as an earlier feature, maybe of the Late Neolithic, and perhaps then integral in some way to the use of Stonehenge itself (Phase 2: Cleal *et al.* 1995, 155–61, 482). Being palisaded, parallels have been drawn with similar ditches, forming the perimeters of large enclosures, at Mount Pleasant, Dorset, and at West Kennett, Wiltshire (ibid.). This attribution remains to be decided (see below), but for the meantime we can note that the ditch has a distinct magnetic signature (of some 5nT) and has been traced by the magnetometer very clearly, both in its passage past Stonehenge (A on Fig. 6) and, again, where it passes close to the elbow of the Avenue (Fig. 5). Aerial photography suggests that it extends further in both directions but its association with outlying field systems and artefact scatters is at present entirely conjectural (Richards 1990; Cleal *et al.* 1995).

The Great Cursus

In 1987 a magnetometer survey was recorded over the eastern terminal of this monument (Gater 1987). The ditch was clearly detectable and could be traced as it turned from the south side of the Cursus northward to form the terminal. The response to the northern ditch was obscured by interference from a modern fence. An internal ditch was located as well, orientated SW-NE, as were a number of anomalies that could be interpreted as pits.

Later, in 1988, a magnetometer survey was undertaken by the AML alongside the eastern flank of the long barrow (Amesbury 42) which marks the eastern terminus of the Cursus. This clearly detected the barrow ditch, and an outlying and probably unrelated ditch, but no other anomalies of significance were found (Payne and White 1988).

The Lesser Cursus

Magnetometer survey of parts of the Lesser Cursus was undertaken by the AML (Bartlett 1988b) in advance of selective excavation by the Stonehenge Environs Project (Richards 1990, 72–93). Since then the entire monument and its surroundings have been surveyed as part of the archaeological assessment associated with the selection of a new visitor centre site (Bartlett and Clark 1993). The result of this substantial survey is a very striking image (Fig. 8) of the Lesser Cursus which not only refines the precision of the aerial

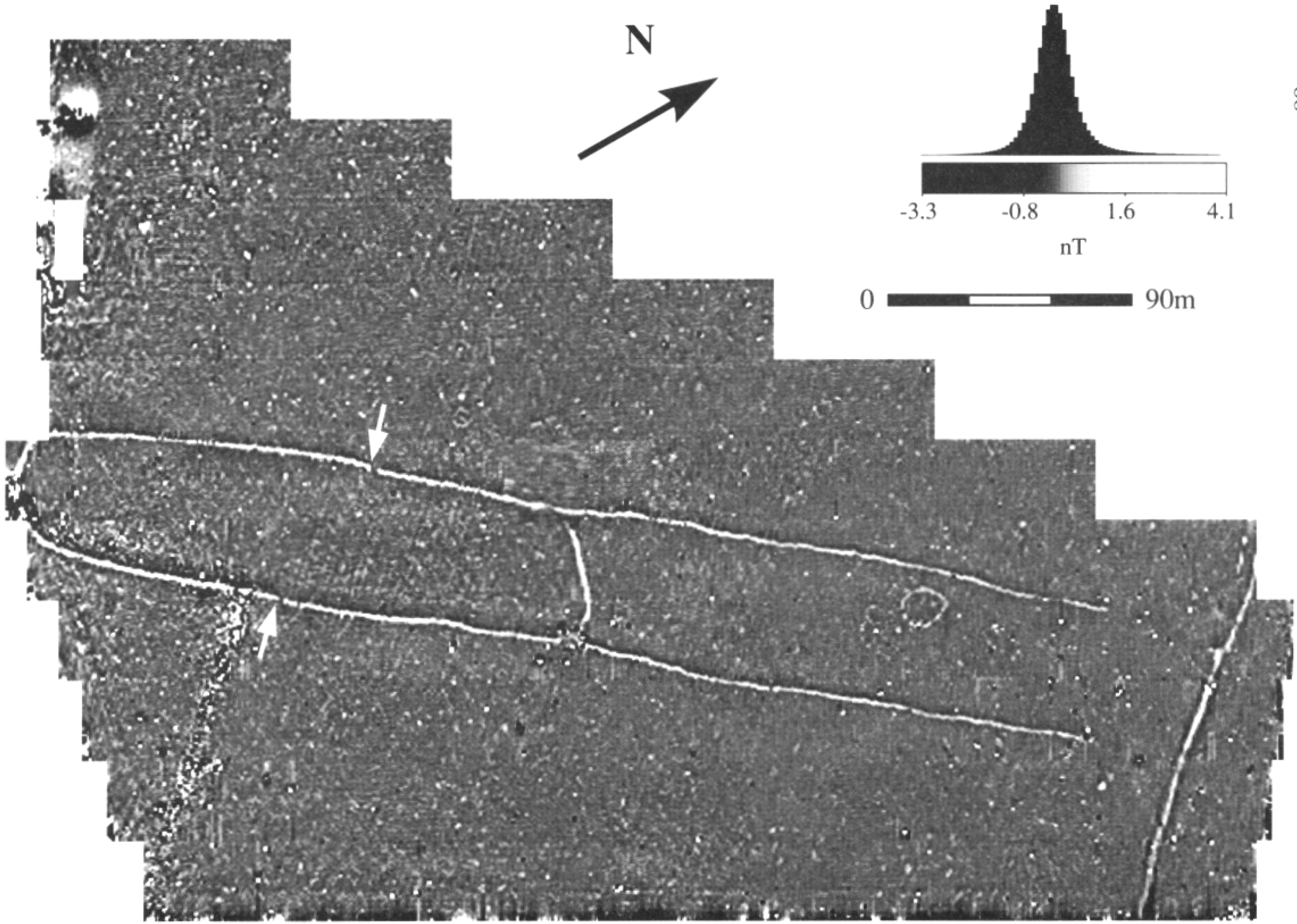


Figure 8. Greytone plot of the magnetic data obtained over the Lesser Cursus in 1993 (data courtesy of A. Bartlett).

photographic record but also adds a new feature: an irregular oval enclosure, some 14–15 m across, situated off-centre near the eastern end of the monument. Some pits appear to be associated with this, both inside and outside. Pits also seem to be scattered about sparsely within the cursus and, more profusely, to the north of its western half. There are hints of small ring ditches here and there, too, although both these and many of the pit-type anomalies may arise from naturally caused depressions in the subsurface (ibid.). Of some considerable significance to the interpretation of the use of the cursus must be the narrow gaps (approximately 2 m across) that have been detected in both the northern and (less certainly) the southern ditches of its western half (arrowed on Fig. 8).

Coneybury henge

The small henge on Coneybury Hill was surveyed by the AML in 1980 using resistivity and magnetometry prior to sample excavation by the Stonehenge Environs Project (Bartlett 1988a; Richards 1990, 124). Both techniques clearly located the henge ditch and resistivity also traced the completely flattened remnant of the bank. Along with MS measurements they also showed evidence of the plough damage to the site. The magnetometer survey (Fig. 9A) was not able to discriminate anomalies of much significance within the henge (despite the presence of shallow pits around its centre) but did isolate a very distinct anomaly outside it, some 12 m to the north of the henge ditch. On excavation, the cause of this was found, with some surprise, to be the filling of a substantial Early Neolithic pit (Richards 1990, 40–61, fig. 24), extraordinarily rich in lithic, ceramic and faunal remains. So unusual is this feature that it has become known in the literature as the 'Anomaly'. It has provided the earliest Neolithic radiocarbon determination from the Stonehenge area. Altogether, 'a neater summary of the elements traditionally taken to characterise the Neolithic could hardly have been achieved if an archaeologist had been sent out to create a time-capsule representing the period' (Cleal *et al.* 1995, 474). The location of this time-capsule, no mere happenstance, is a vivid demonstration of the potential of geophysical survey.

Also now embedded in the literature are the results from measurement of topsoil MS across the site, made after the initial surveys (Clark 1983a, 1983b, 1986, 1996). The MS values showed a distinct area of enhancement at the centre of the henge that did not correspond with any surviving subsurface features. There was, however, a corresponding increase in density of burnt flint in this area and it has been surmised by Clark (ibid.) that both sets of data combine to indicate a burning event (such as a bonfire) contemporary with the lithic material. Implicit in this interpretation is the inference that a spatially discrete MS signature (if not the result merely of recent localised exposure of ancient soil by ploughing) may be retained in the topsoil for thousands of years. Samples of topsoil from the site were also analysed for their phosphate content but without any obviously significant outcome.

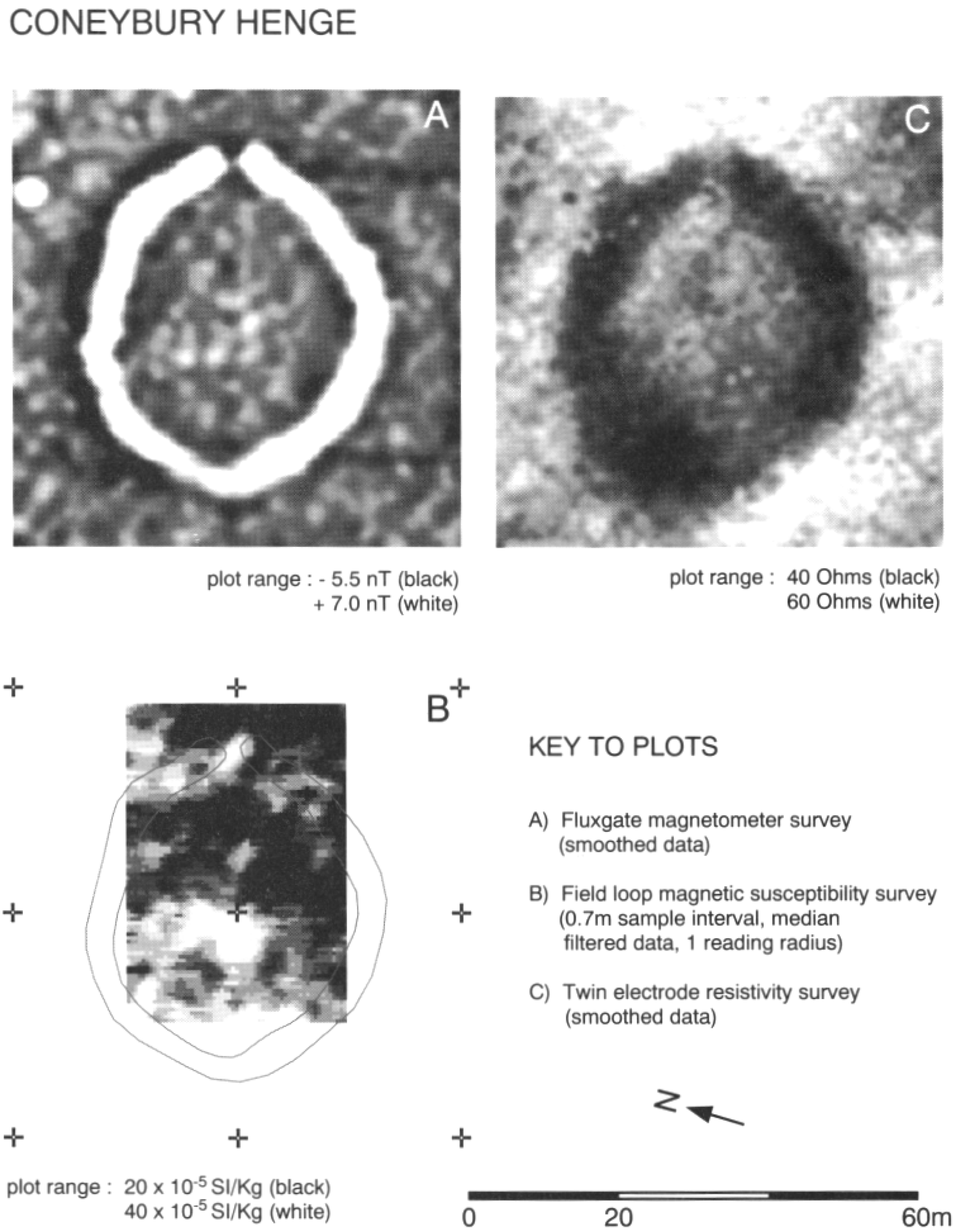


Figure 9. Greytone plots of (A) magnetometer and (B) MS and (C) resistivity data over the Coneybury henge.

Durrington Walls

The 'superhenge' at Durrington has been the target of geophysics on more than one occasion. In the first instance, in conjunction with the rescue excavations of 1966–8 (Wainwright and Longworth 1971), A.J. Clark, then of the AML, undertook a resistivity survey to trace the course of the ditch. This was supplemented by sample coverage of the interior with a proton magnetometer (RCHM(E) 1979). This survey, although only partial (RCHM(E) 1979, fig. 10), successfully confirmed the existence of a small ?Iron Age enclosure abutting the northern perimeter, a double-ditched circular enclosure near the centre of the henge, a number of putative ditches and a scatter of pits—concentrating particularly within an area to the north of the centre of the monument. The identification of several anomalies as pits was confirmed by augering. Because of the incomplete coverage, however, and the coarse survey interval (5 ft) within the sampled areas (50 ft × 50 ft), it was recommended that a complete survey with more modern equipment should be undertaken (RCHM(E) 1979, xv, 18).

This was first attempted by the AML in 1989, but was not fully realised until 1996 when the entire area west of the former line of the A345 was re-surveyed in detail using Geoscan gradiometers and a sampling interval of 1.0 m × 0.25 m. More detailed magnetometer sampling (0.5 m × 0.25 m) and resistivity survey (0.5 m × 0.5 m) was undertaken over selected areas. A full technical report on these results will follow further fieldwork (see below) but we can present a summary here (Figs 10 and 11).

The topography of the henge interior resembles an arena. The uppermost ground, along the western perimeter, encircles a shallow combe that descends south-eastwards across the centre of the monument towards the river Avon. The double ring-ditched feature visible on Crawford's aerial photograph (Crawford 1929), and located by Clark (A on Fig. 11), lies almost in the bottom of this combe in a position commanding a view over much of the eastern half of the henge. The recent survey shows that this feature is the largest (with a diameter of 35 m) of a group of at least four enclosures strung out centrally and very roughly at right angles to the axis of the combe. To the south of the central circle is a much smaller one (B), 12 m in diameter, whilst to the north is an open-ended oval enclosure (C), about 17 m long, with a dense cluster of pit-like anomalies immediately to its east. To the north of this there is a sub-rectangular enclosure (approx. 11 m × 10 m) also apparently with an opening (D). About 100 m to the south of this group is an outlier, a further open-ended oval, approximately 14 m long (E). The openings of the three features where such gaps are detectable in their circuits, all face downslope towards the combe bottom at the centre of the henge. It is noticeable that the survey does not confirm the presence of an inner ring within the larger circle; no coherent pattern of anomalies is visible within it.

As predicted by the proton magnetometer survey, there is a clear concentration of anomalies, many of which must be pits, to the north of the centre of the henge. What is immediately apparent, however, is that (with some significant exceptions) these respect a

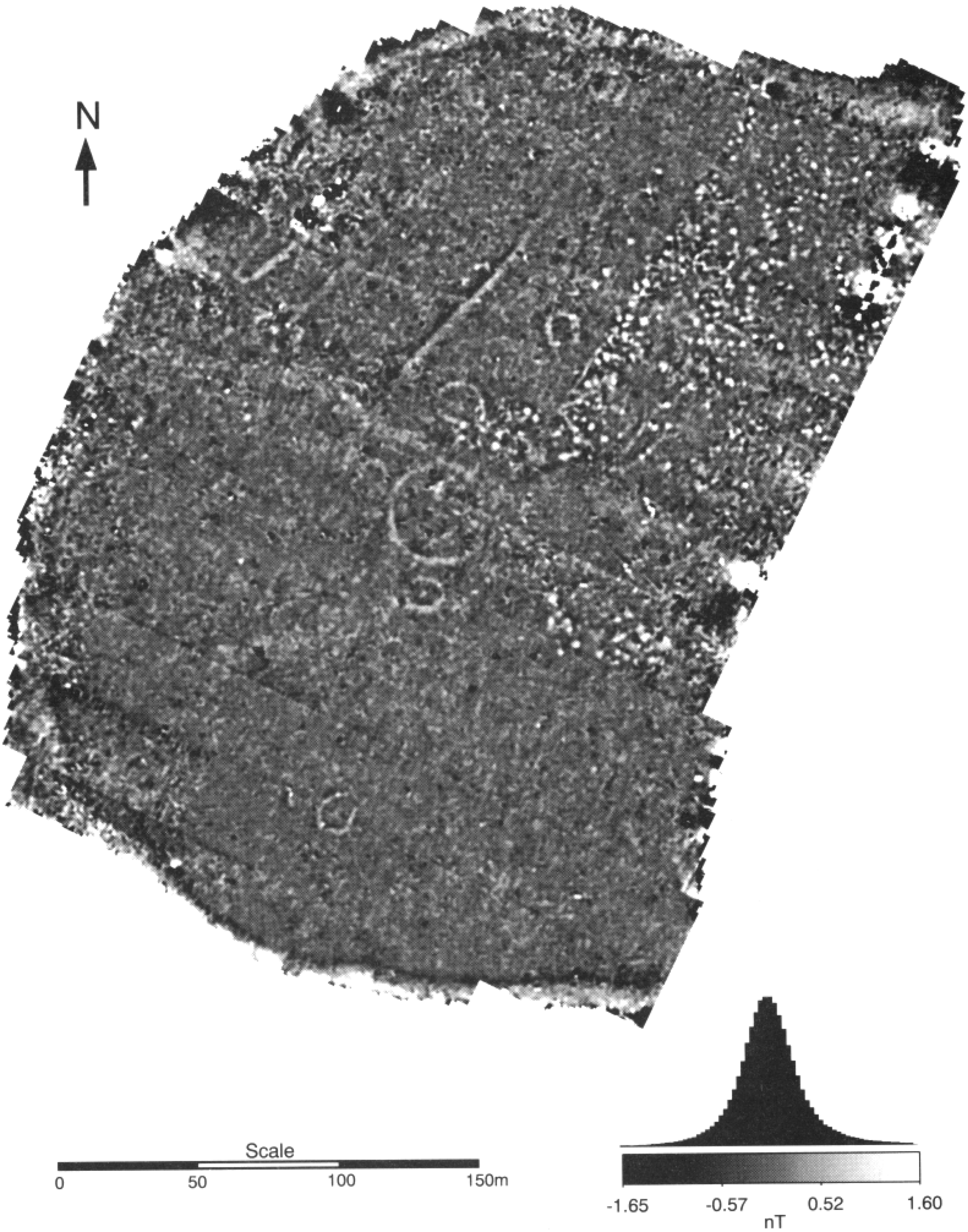
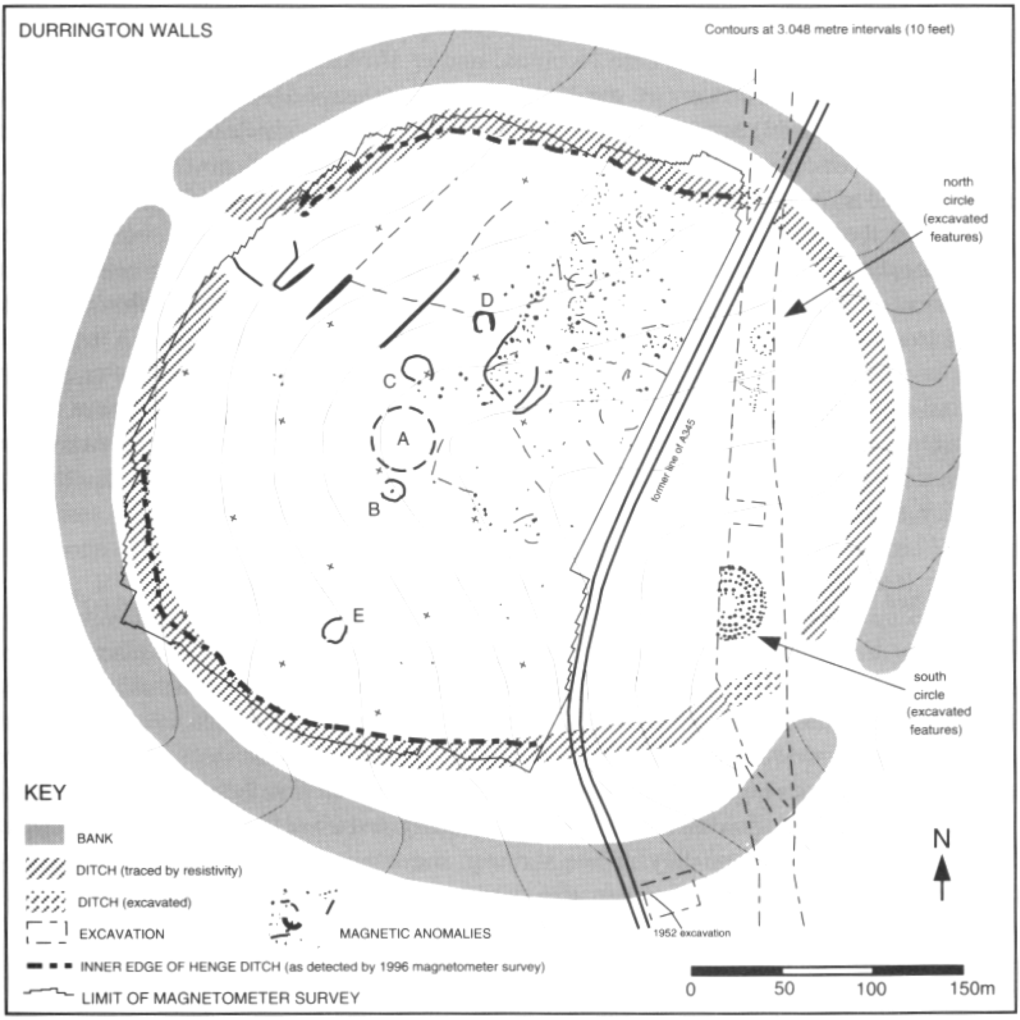


Figure 10. Greytone plot of 1996 magnetic data from the interior of Durrington Walls.



(Plan based on RCHME 1979)

Figure 11. The main archaeological features detected by the magnetometer survey within Durrington Walls.

largely undetected boundary running NE-SW which separates them from the aforementioned circles and ovals. The alignment of this 'boundary' is approximately parallel with lengths of ditch located further to the north-west and perhaps linked with the Iron Age enclosure there. There are separate clusters of pits in the bottom of the combe. Apart from the one oval ring ditch, archaeological anomalies of any description are noticeably absent from the southern half of the area surveyed.

A full interpretation of these very promising survey results must await a more detailed analysis and further fieldwork (see below). A first generalisation suggests that the circles and 'hengiform' ovals are of Late Neolithic and/or Bronze Age affiliation. As a group they are certainly reminiscent of the barrows on Stonehenge Down (above and Fig. 7). The smaller circle (B) appears to contain a central anomaly which may be a grave pit. At present no clear evidence has yet been obtained for circles of post-holes that could be compared to Woodhenge nearby, or to the Northern and Southern Circles of Durrington, now under the modern road. It remains a strong possibility, though, that such structures are concealed within some of the clusters of 'pit-like' anomalies near the centre of the monument. It is likely, however, that many of the pits and most of the ditch alignments are of Iron Age date, in keeping with other evidence for activity of this date in the immediate locality (RCHM(E) 1979; Wainwright and Longworth 1971). With this latter activity in mind it is open to speculation that the northernmost, sub-rectangular, enclosure (D) in the central group may also be of much later date than its neighbours. It appears to be different to the sub-rectangular double-ditched feature recently recognised at Avebury (Bewley *et al.* 1996).

Woodhenge

Resistivity traverses across the ditches of both Durrington Walls and Woodhenge were undertaken by A.J. Clark as part of his wider study of the effects of seasonality upon the resistivity response (Clark 1975, 1996). The results showed that the massive Durrington ditch remained detectable throughout the year as a low resistance anomaly. More problematically, the response from the much smaller ditch at Woodhenge was more sensitive to seasonal variation in moisture balance, being negative for most of the year but changing to a positive anomaly in late summer and autumn. As remarked at the beginning of this paper both ditches were also used to test GPR.

Vespasian's Camp

Very restricted magnetic and resistivity surveys in 1995 within this Iron Age fortified enclosure overlooking the Avon west of Amesbury, south of the Stonehenge Road, revealed little else beyond twentieth-century ferrous disturbance and landscaping. A ring-ditch, perhaps a barrow, was found abutting the southern rampart (Cole 1995).

The landscape

Now that we have summarised results from geophysical surveys that have taken place over some of the better known monuments in the World Heritage Site, it is necessary to look briefly at those from other surveys in this area.

The Stonehenge Environs Project

A number of geophysical surveys were undertaken by the AML in advance of test excavation by the Stonehenge Environs Project (Richards 1990; Bartlett 1988b). Reference has already been made above to the surveys of the Coneybury henge, the Lesser Cursus and part of the Avenue, all of which were contributions to the wider Project. The magnetometer survey that detected the northern ditch of the Avenue was situated to cover part of an extensive flint scatter on King Barrow Ridge (Site W59). Over twenty anomalies were located within an area of 0.54 ha and sample excavation of four of these revealed a total of five Neolithic pits of varying ages (Richards 1990, fig. 75). This result is suggestive that at least some of the remainder of the anomalies are probably also pits (rather than natural features, which also occur) and support the excavator's contention that a palimpsest of ?sedentary activity is represented on this part of the ridge.

Small magnetic surveys and MS measurements were also made at Fargo Wood I and II (Sites W32 and W34), and on Wilsford Down (Site W31), all surface artefact scatters, but none of which produced significant geophysical results (but see Entwistle and Richards 1987). It is worth noting that the survey on Wilsford Down located several magnetic anomalies interpreted as possible pits or short lengths of ditch, but which on excavation were shown to be natural features (Richards 1990, 159).

The Stonehenge Environs geophysical surveys were an essentially research-led element of that Project, conducted in the early 1980s. Since then, however, the environs of Stonehenge have seen a much more extensive investment in geophysical survey necessitated by the obligation to make a thorough archaeological assessment prior to the acceptance of planning initiatives (Department of the Environment 1990).

Some of these latter surveys touch upon major field monuments (e.g. the North Kite), but the majority cover swathes of outlying landscape where it has been a major consideration to try and *avoid* overlap with significant remains. In most of these cases, geophysical survey was undertaken as a precautionary measure, to ensure that unsuspected remains were indeed not present. However, if anomalies were located, such survey should be able to contribute to an assessment of their archaeological importance and act as an aid to the targeting of further field evaluation. This 'development-led' survey coverage is very complex in its distribution (Fig. 1) and much of it has not resulted in major new discoveries. For simplicity's sake we will refer only to surveys where positive results were obtained, and categorise the surveys according to the particular development concerned in each case.

Visitor Centre Sites and approach routes

Surveys related to the various options for re-siting visitor facilities began in 1990 when the AML surveyed parts of an eastern approach to the proposed Larkhill Visitor Centre site (AML archive). This was followed in 1991 by a much more extensive programme of magnetometer and MS survey which covered the proposed Larkhill site itself, the Western Approach to it from the A344, and long narrow strips of ground to either side of the A344 and A303 (Bartlett and Clark 1991). This survey was commissioned from A.D.H. Bartlett and Associates by Debenham, Tewson and Chinnocks and by Timothy Darvill Archaeological Consultants, who were coordinating the project on behalf of English Heritage.

The resulting report (ibid.) notes that the survey responded effectively to a number of known and extant features, particularly round barrow ditches and the western ditch of the Avenue. Ditches corresponding with those sectioned by F. and L. Vatcher close to King Barrow Ridge were located. Elsewhere, findings throughout the survey were in general magnetically weak and scattered anomalies were tentatively interpreted as pits or short linear features, an unknown proportion of which may be natural in origin (ibid.).

In 1993 a further very extensive survey was conducted over other optional routes for a Western Approach to the Larkhill Visitor Centre (Bartlett 1993). This detected a number of archaeologically significant features, including ditches or earthworks associated with the Durrington Down and Fargo field systems known from aerial photography. There appeared to be a relative lack of other features, except occasional pits.

Finally, in 1994, another proposed Visitor Centre Site, at Countess Roundabout, north of Amesbury, was surveyed, as well as its access corridor, extending along the north side of the A303 to King Barrow Ridge. Again, there was a good response to known features but, apart from these, few anomalies of any archaeological significance were found (Bartlett 1994).

Upgrading the A303: Amesbury to Berwick Down Route Options

Yet more survey coverage has been undertaken, commissioned by the Highways Agency, as a result of plans to upgrade or re-route the A303 through the World Heritage Site. These surveys, undertaken by Geophysical Surveys of Bradford (GSB) for Wessex Archaeology, took place between 1992 and 1994 (GSB 1992a, 1992b, 1993, 1994). Unfortunately, as elsewhere around Stonehenge, ferrous disturbance prevails in much of these surveys, especially near roads, tracks and over pipes and the sites of military and other installations. However, they have succeeded in confirming the presence of known archaeological features, and have added detail to some of these. Although large areas seem to be mostly devoid of definite archaeological anomalies, a significant number of previously unknown features were located, in widely separate parts of the landscape. Although a detailed review of all these is not possible here, the more important findings can be summarised.

Near Scotland Farm (SU 067 410), over 5 km west of Stonehenge, magnetometer survey mapped in detail a ditched oval enclosure (approximately 175 m × 90 m) the outlines of which were previously visible as cropmarks. The survey revealed, in addition, an abundance of related features, especially pits, as well as evidence for adjacent (but not necessarily contemporary) enclosures (Fig. 12). Some 300 m to the north-east a ring

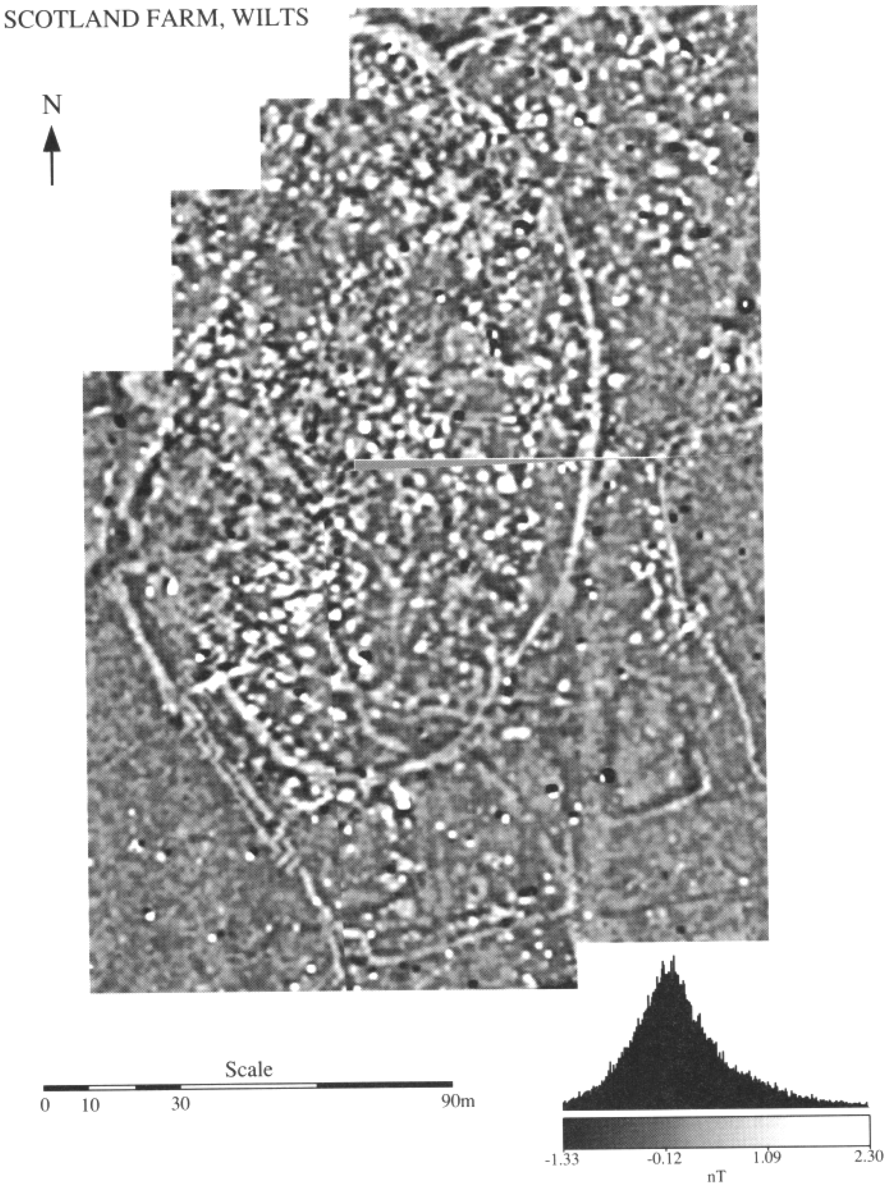


Figure 12. Greytone plot of the magnetometer survey undertaken by Geophysical Surveys of Bradford near Scotland Farm, Winterbourne Stoke (data supplied by GSB and published by courtesy of the Highways Agency).

ditch about 32 m in diameter was located for the first time and interpreted as a barrow, or perhaps a henge (GSB 1994). Other surveys over the 'Brown Route Options' to the north-west and north-east of Stonehenge yielded occasional linear anomalies and generalised scatters of pit-type anomalies (ibid.).

Nearer Stonehenge, at the Longbarrow Crossroads, another cropmark enclosure (approximately 60 m × 80 m) was located, bisected by the A303, west of the roundabout. It contains a number of magnetic anomalies suggestive of internal features. Just to the north, a ring ditch, about 18 m in diameter and with a weakly defined (perhaps interrupted) ditch circuit was newly identified. To the south of the roundabout various linear ditches and a number of pits were found. Very clearly visible to the magnetometer (Fig. 13), as also from the air (RCHM(E) 1979), is a small segmented ring ditch (Winterbourne Stoke 72) and a larger ring ditch (Winterbourne Stoke 74). The survey clearly demonstrates that this latter circle has a single entrance to the east, indicating that it is probably a henge (GSB 1992b, figs 8.1A-8.4A). Neither circle appears to have detectable internal features.

Of the other survey areas south of the A303, existing aerial photographic evidence was substantiated. Ferrous disturbance and an incomplete coverage have frustrated further definition of the North Kite (GSB 1992b, 1993). Of significance, however, may be the detection of a narrow ditch running parallel to the western side of the Kite, and about 14 m outside it, which could be a counterpart to the one known to run parallel with the eastern limb of the enclosure (Richards 1990, 184). Evidence for features within the Kite is complicated by the presence of scattered ferrous objects.

Another new discovery, but without any known association, is that of a weak magnetic anomaly to the south of Stonehenge Cottages (SU 1347 4195) which clearly defines a ditched square enclosure with sides of about 17.5 m (GSB 1992b, fig. 6.1A). Further to the west, just to the south of the junction of the A344 with the A303, a length of curving ditch, not previously mapped (although perhaps representative of a former road alignment) has been traced for about 150 m, running across Stonehenge Bottom (GSB 1993).

On the south-western flank of Coneybury Hill, traces of the ditches of a field system and other possible enclosures have been located, illustrating again—as elsewhere in this landscape—that magnetic survey is capable of extending the cropmark evidence for so-called 'Celtic field systems'. Evidence for actual settlement, that is the sites of habitation activities, is less obvious—except where enclosure ditches are present and can be seen to be associated with dense concentrations of features, as at Scotland Farm. Where traces of settlement are more diffuse, and/or more poorly preserved, they are very difficult to identify. On Coneybury Hill, for instance, the combined results of topsoil MS surveys, magnetometer survey, and recording of concentrations of surface lithic material were inconclusive (GSB 1993). Like so much of the magnetometer coverage around Stonehenge there are large areas of negligible magnetic activity throughout which are scattered, thinly and seemingly at random, many 'pit-like' anomalies. Whilst a lot of these may be spurious, caused for instance by natural features or more deeply buried ferrous litter, an unknown

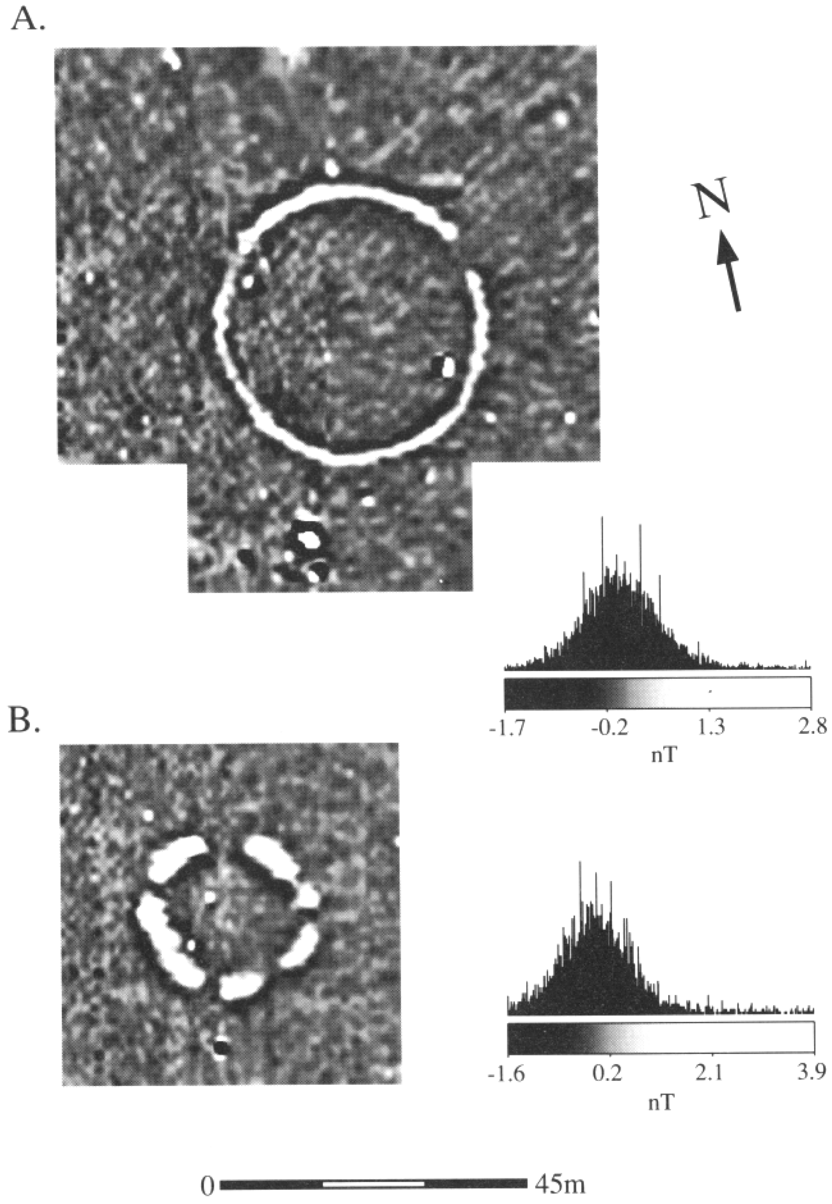


Figure 13. Greytone plots of the magnetometer surveys undertaken by Geophysical Surveys of Bradford over Winterbourne Stoke 72 and 74 (data supplied by GSB and published by courtesy of the Highways Agency).

number may yet represent the only indications of genuine 'sites'. The interpreters of geophysical survey plots are loath to omit reference to such anomalies just in case this is so.

Discussion

It would be useful now to summarise some impressions gained from the foregoing review and then to suggest ways in which geophysics may be able to contribute to archaeological research in the Stonehenge area in the future. That these techniques must have a place in such research should by now, it is hoped, be fully apparent. Before concluding we shall suggest a number of specific targets for future survey.

Of the geophysical methods so far applied in this area the most favoured, by a large margin, is magnetometer survey. This is explained not only by its practical advantage of speed of operation, but by the fact that both the surviving archaeological features themselves, and the contrasting magnetic qualities of the local chalk bedrock and its associated soils, often conspire together to provide a good response. This is illustrated again and again throughout the area, typified for instance by the surveys of the Lesser Cursus and the interior of Durrington Walls and the Coneybury henge. Some important categories of features can easily be missed, however. This is particularly so of the smaller and less magnetic ones such as gullies, post- and stake-holes, and also of some pits and graves which may offer only a poor magnetic contrast between their fillings and the surrounding chalk.

A further constraint on the use of magnetometry, which can limit and, in many extreme cases, entirely nullify its efficacy, is where the landscape is contaminated by recent magnetic debris. This is unfortunately the case, for instance, over the sites of the Stonehenge Aerodrome, the former Horse Isolation Hospital at Fargo and along the margins of most of the roads. Ferrous litter can be widespread elsewhere too, but, if not too dense, its effects can usually be filtered out—as has fortunately been possible at Durrington Walls where rubbish dumping has been a significant problem.

Despite these constraints it has been demonstrated that magnetometry can be extremely effective. As a general rule, it has been shown to respond to the same type of features as those identified by aerial photography. It may thus be used to locate these accurately on the ground and can considerably refine and add to their detail. Examples of this include the enclosure complex at Scotland Farm, the Lesser Cursus, the interior of Durrington Walls, the elbow of the Avenue, the Palisade Ditch, and the Stonehenge Down barrows. Magnetometry has located many new features as well, for example those within Durrington Walls, the Coneybury Anomaly, the ring ditch within the Lesser Cursus, and various pits and ditches from many other locations. Magnetometer survey will also, of course, provide equivalent information to that from aerial photographs over many areas which are for one reason or another not amenable to the recording of crop-marks or soilmarks.

Although there has been much technical improvement over recent years resistivity survey is still much more labour-intensive than magnetometry and responds to a more restricted range of archaeological features. In the Stonehenge area, where ditches and pits predominate, magnetic methods of detection are quicker and more effective. However, if the prevailing moisture conditions are favourable, resistivity is probably better at locating stone settings, and can be sensitive to the presence of severely eroded and flattened earthworks, as has been demonstrated at both Stonehenge itself and at Coneybury. It would be very valuable to see a much wider (and repetitive) coverage by this method of carefully targeted sites.

Other methods of geophysical detection have been attempted only experimentally in this area, for instance at Woodhenge and Durrington, but have not yet played a significant role (but see below). Topsoil magnetic susceptibility survey has been used fairly extensively in support of the interpretation of magnetometer data rather than as a prospecting technique in its own right. 'Pit-like' anomalies in a magnetometer plot may be more securely interpreted as genuine archaeological features when linked with locally elevated topsoil MS values (for example as suggested for the area to the north-west of the Lesser Cursus: Bartlett and Clark 1993). In some instances, such as at the Coneybury henge, MS may be used with other geophysical and excavated data to arrive at specific interpretations of site function. Phosphate measurements, whilst used routinely during the Stonehenge Environs Project, with MS, seem to have only shown modest potential for generalised statements on site and feature function and as yet have little, if any, value for preliminary site location (cf. Entwistle and Richards 1987).

The future

There are two linked aspects to the question of future geophysical research at Stonehenge and within its environs. These may be taken in either order, but here we suggest that firstly, it is necessary to define archaeological imperatives and then, secondly, to apply and develop relevant geophysical methodologies to tackle them. Previous experience, summarised above, already allows us a fair appreciation of both the archaeological and technical problems involved.

The archaeological aspect needs to be viewed at several scales. At the largest and most Utopian, one should not shrink from aiming at the total non-destructive examination of the entire World Heritage Site, 6.8% of which has already been magnetically surveyed. This would extend the detailed coverage recently given to Stonehenge itself, and more, to most of the 2666 ha of its surroundings. It would ensure, as far as would be technically feasible at the time, that every buried feature in the area would be mapped. When linked to the surface record (Batchelor, this volume) this would complete the ultimate database for the World Heritage Site.

Aerial remote sensing offers the nearest approach to this ideal. The products of about 90 years of flying have already provided an extensive and detailed record of earthworks, cropmarks and soilmarks, but unsuitable surface conditions preclude total coverage. Airborne and satellite multispectral scanning may in future make up for some of this shortfall but presently lacks the resolution of conventional air photography (Fowler and Curtis 1995; Fowler 1996).

As more land is developed, and as conservation in the World Heritage Site gathers pace, a greater proportion will be taken out of cultivation and will be less amenable to aerial survey. This places a greater onus on ground-based methods. Although total survey may remain unrealistic for the time being, developments in field methodology and in computer capacity and processing power nonetheless allow the prospect of a vastly increased survey coverage. If the whole World Heritage Site cannot be surveyed, then there is at least a reasonable expectation that very large areas within it can be. This could be made possible by the deployment of multiple arrays of magnetometers drawn behind wheeled vehicles and the use of continuous contact resistivity systems also mounted on vehicles. Prototypes of both systems are already in use elsewhere (Clark 1996, 163). EM conductivity instruments could presumably also be applied in this way and, moreover, are theoretically capable of delivering both conductivity and MS data without arduous sampling or the need for ground contact. The open and unobstructed expanses of Salisbury Plain would lend themselves ideally to the detailed coverage of several hectares of open ground per day.

Even without such mechanisation the present methodology has already resulted in an awesome coverage which could and should be extended by whatever means. It makes little sense, for instance, for the survey of the Stonehenge Triangle to be constrained by the geometry of the modern road network when it could be extended widely in every direction. Perhaps a priority in the first instance should be to work northwards so as to embrace the vaster spaces around and within the Avenue and the Cursus. Such large surveys could also be targeted at 'blank' areas, apparently with a dearth of monuments, in the search for the still elusive settlement areas of the Neolithic and Bronze Ages. It has been suggested (Batchelor, this volume) that such a search might profitably be aimed within areas that fall outside those defined by intervisibility between monuments.

At a more reduced scale of enquiry, geophysical methods can be focused down to target particular site complexes, to individual monuments amongst them, or even to components within such sites. There are many quite specific archaeological questions that can be addressed at these levels.

In any consideration of the monuments themselves one has to tackle Stonehenge itself first of all. However, it is our view that, for the time being anyway, there is very little that can be done that will add very significantly to existing knowledge here. The amount of modern infrastructure amongst and around the stones, combined with the irregular honeycomb of intercutting features and backfills, places near insoluble difficulties on geophysical survey interpretation.

It would not do to be too pessimistic, however. It has been suggested (Cleal *et al.* 1995, 492) that detailed geophysical survey of the Ditch and Bank would 'establish the occurrence of further causeways and structures', and this is certainly worth attempting. An even more detailed resistivity sampling interval might be necessary, however, and the survey should be carefully timed to coincide with maximum moisture contrasts. This could be achieved by monitoring resistivity response at selected locations throughout a full year (or more) in order to predict exactly at what time to achieve the best results. It might, in any case, be worth repeating resistivity survey at different times of the year. Such surveys, apart from refining detail of the Bank and Ditch, might also pick up other information, missed by the previous survey, from elsewhere within the monument.

The question of the morphology of the Ditch could also be approached by resistivity profiling, using narrowly spaced multiprobe arrays placed at frequent intervals across the Bank and Ditch. Resistivity profiling, which generates pseudosections or tomographic sections giving an indication of resistivity variation with depth below a linear array of electrodes, is still a relatively undeveloped technique in archaeology (Noel 1992; Szymanski and Tsourlos 1993). Some considerable advances will be required before it will be able to provide the quality of resolution demanded of the Stonehenge enclosure Ditch. There is a possibility that ground-penetrating radar may also offer some prospect of mapping the Ditch in three dimensions, but this technique has not yet matched elsewhere the high expectations generated for it in the 1980s (e.g. Stove and Addyman 1989). The Ditch is very shallow and its fill generally poorly differentiated from its surroundings in terms of clearly detectable dielectric interfaces. Recent experimental work on another shallow chalkland site has been unsuccessful (Meats and Tite 1995).

Both resistivity profiling and GPR could be used in an attempt to target certain areas between the Ditch and the stone circles. Obvious targets of interest, if they cannot be tested by excavation, are the unexplained resistivity anomalies at A and B. Both methods could be used to search for buried megaliths.

Both the Palisade Ditch and the Avenue call for further exploration. If the former is indeed a comparable feature to other Late Neolithic palisades then determining its full extent should be a priority (Cleal *et al.* 1995, 483, 493; Bradley, pers. comm.). The Avenue deserves re-survey of those areas already covered, by both detailed magnetometry and resistivity, and the extension of these surveys along its entire length and, importantly, widely to either side of the alignment. Particular unresolved issues that such surveys could address include the presence or absence of stone placements (see above, and footnote), and the nature of the Avon terminal. Although previous survey has shown that the Avenue does not split into two at the elbow, there remains an enigmatic soilmark that extends the north-eastward alignment of the Avenue well beyond the elbow towards the eastward end of the Cursus (Cleal *et al.* 1995, 313–14, fig. 179). This too deserves to be explained.

Magnetometry has demonstrated how effective it can be at locating pits, and this suggests that further survey to identify these important features would be warranted. There would clearly be advantage to extending the King Barrow Ridge survey, for instance, or to look closely at the area of the Chalk Plaque Pit (Harding 1988), or in the area of Woodhenge. Large pits with a magnetically well enhanced fill are usually easily identifiable as archaeological features (particularly if they are associated with other very suggestive evidence such as ditched enclosures). However, it is worth pointing out that excavation of weaker and less well-defined magnetic anomalies, which are not so associated, has shown that these may often be non-archaeological. This leads to an unsurprising diffidence when it comes to interpreting the large numbers of 'pit-like' anomalies that pepper so many of the magnetometer plots from around the outlying areas of Stonehenge. Are they really artificial pits, or not? Are they of ritual, domestic or industrial origin? These problems are not easily resolved. Perhaps augering each one would help, but this is not only potentially damaging but also time consuming—as would be any profiling method (even if these could be fully relied upon). Computer modelling of pit morphology (Sheen and Aspinall 1994) could provide clues that might help, for instance, to distinguish a storage pit from a tree-throw hollow but this approach has yet to be tested in earnest on a large scale. MS survey might well give a little weight to one interpretation or another, but would probably not be conclusive. This is therefore an area of interest where more research is needed to develop reliable means of interpreting these anomalies. And it should be added that such research would also benefit, and itself inform, a necessary study of the nature and rates of chalk degradation in the Wessex landscape.

Despite problems such as this it is clear to us that the most valuable geophysical technique in the immediate future will continue to be magnetometry. It is already capable of a high degree of sensitivity, as illustrated by the successful detection of the very weak signals from features such as the central ring ditch within Durrington Walls. Where magnetic contamination is at a minimum, the local chalkland geology can offer a magnetically almost inert background against which very subtle signals from significant but slight features may be detectable. There is therefore scope not only for extending the sort of fluxgate gradiometer survey already in use, but also for exploiting even more sensitive magnetometers at even narrower sampling intervals. Commercial portable caesium magnetometers are now available in the UK but are as yet barely tested on archaeological sites. However, surveys with caesium magnetometers by German archaeogeophysicists have already proved that these instruments have powerful abilities which are at least comparable to those of fluxgates, and potentially much more so (Faßbinder 1994; Faßbinder and Irlinger 1994). It should be a priority, then, to experiment with such instruments, and parts of the Stonehenge area would be well suited for this. Although the magnetic contamination around Stonehenge itself is discouraging, caesium magnetometry might be a sensible approach to exploring for post- or stone-settings near or beyond the Ditch, for instance on the axis defined by midsummer sunrise and midwinter sunset. The technique would be more effective, however, in the identification of such features in areas where the magnetic background is much more uniform: the sites of 'henge'-type ring ditches such as Winterbourne Stoke 72 and 74 (Fig. 13) would be worth investigating for interior features, as would the newly located sites within Durrington Walls.

If the location of stake-holes is one end of a spectrum of spatial resolutions, then at the other end are the grosser types of feature such as mines and shafts about which so little is known in this area. For instance, three open-cast pits and two shafts 1.5 m deep, interpreted as flint mines, have been excavated near Durrington (Booth and Stone 1952), and their immediate vicinity would be worth investigation for traces of related activity. Magnetometry, resistivity, GPR, and possibly microgravity techniques (Linford forthcoming) would find applications here.

Another opportunity to use GPR has arisen as a consequence of speculation that pond barrows may conceal the sites of shafts such as that found below Wilsford 33a to the south-west of Stonehenge (Ashbee *et al.* 1989). It was suggested that GPR might be one way of testing this hypothesis (ibid. 141) and to this end trial transects were made in 1995 by Mr E.W. Flaxman and Mr John Trust over the Wilsford Shaft itself, as well as over other pond barrows nearby, in the Winterborne Stoke Group (WS 12 and WS 3a) and the Lake Group (WS 78 and WS 77: Flaxman nd). A GSSI SIR2 kit was used and transects were made with both 500MHz and 100MHz antennae. The 500MHz profiles of the Wilsford shaft appear to have clearly detected sides of the upper part of its weathering cone but down only to a depth of approximately 1.2 m (Fig. 14). Unfortunately, however, transects over the other barrows did not produce an equivalent reflection pattern and the radar profiles are difficult to interpret without the support of additional field data. Whilst the profiles over the two pond barrows at Winterbourne Stoke were inconclusive they at least do not discount the possibility that shafts may be present; however, the profiles over the Lake barrows seem to indicate a shallow interface at their centres (Fig. 14) and on this evidence the existence of shafts there seems to be in much more doubt. Magnetic and resistivity surveys of these two latter barrows (including an adjacent smaller barrow) were undertaken by the AML in March 1996. The resistivity data (Fig. 14) clearly identify the higher resistance of the surrounding bank and, as might be expected, the interior is mostly of lower resistance. However, in each barrow there is a central core area of high readings, especially pronounced in the centre of the smallest barrow. Whilst such a pattern appears to be consistent with the GPR data from the two bigger barrows it does not provide a ready explanation, except that there is a drier and probably shallower core area in each barrow. The magnetic data illustrate that there is some ferrous contamination near the centre of WS 78, suggestive of a former excavation, but this does not explain the resistivity phenomena observed. Grinsell (1957) records that all three barrows have been interfered with.

These barrows and some of the examples cited above demonstrate that barrows and ring ditches are particularly amenable to geophysical investigation. Not only is there some hope of establishing information on their internal structure and their state of preservation, there is also the possibility that by careful survey of their surroundings, especially with magnetic methods, it may be possible to identify more ephemeral features (such as the sites of cremation pyres). The interstices *between* barrows deserve more attention.

Whilst individual monuments or groups of monuments thus surely provide considerable incentive for further work, it is clear that the greatest benefit comes from the deployment of a combination of several complementary techniques. To realise their maximum

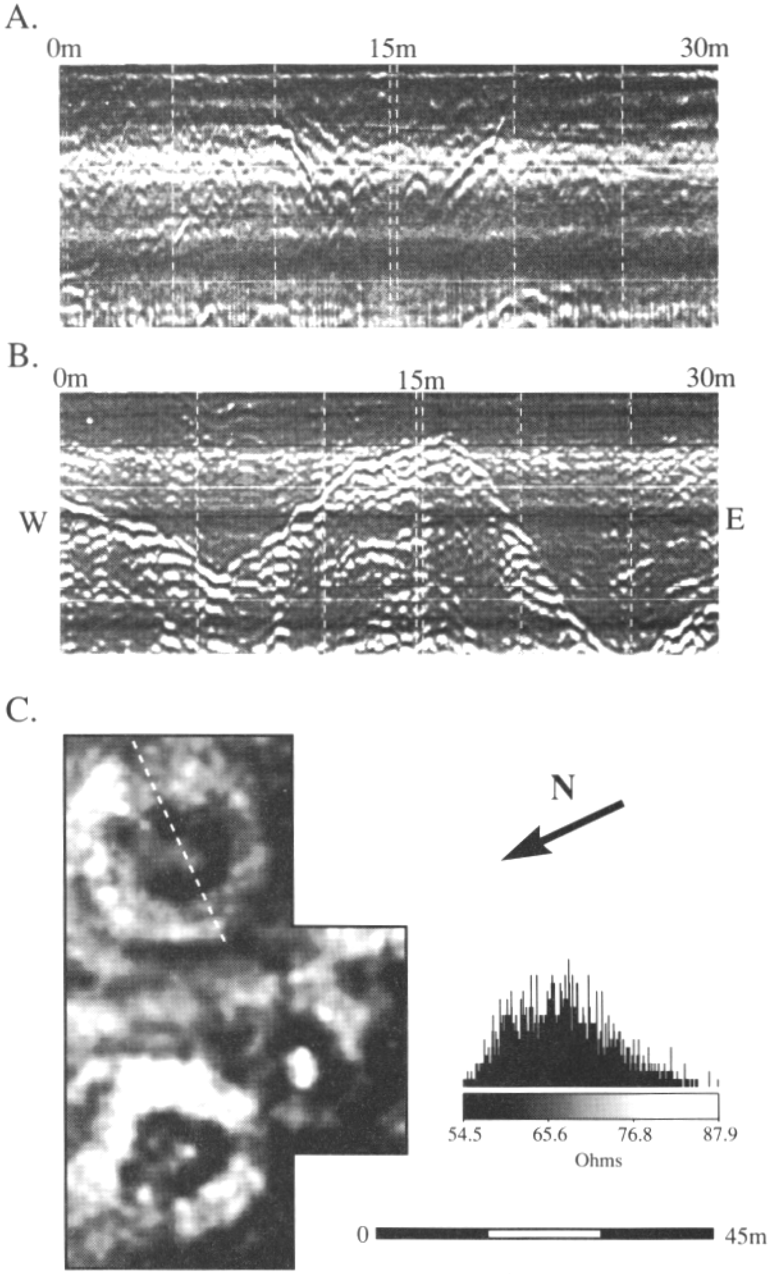


Figure 14. A: Ground Penetrating Radar (GPR) profile across the site of the Wilsford Shaft (1995), B: GPR profile across pond barrow at Lake Down (LVG WS78), C: greytone plot of resistivity survey data over pond barrows LVG WS78, LVG WS77 and LVG WS77A. The position of the profile (B) is indicated. (GPR data profiles supplied by courtesy of J. Trust and E. Flaxman.)

effectiveness, however, it will be necessary to accept that these non-destructive methods should preferably be accompanied by some select corroborative test excavation so that 'ground truth' can inform future research.

Geophysical survey can of course also contribute significantly to the study of the Stonehenge area after its *floruit*. Enclosed settlements and field systems seem first to appear in numbers in the landscape in the later Bronze Age and although Stonehenge seems to be maintained and modified in this period, there is evidence that the landscape is changing in character from a mainly funerary emphasis to more domestic use. The evidence for this period of change could be explored further by targeting geophysical survey on areas containing scatters of later Bronze Age and Deverel Rimbury pottery previously located as surface scatters but not investigated further. Such survey could assess these sites for the presence of associated sealed deposits. The potential of evidence for Iron Age, Roman and medieval activity obviously should not be omitted from such studies, either.

Summary: a possible future programme for geophysical survey at Stonehenge and within the World Heritage Site

We will now summarise briefly the foregoing suggestions for survey targets and also add a few others for which lack of space does not allow for any further digression. Our assumption is that the entire surveyable area should be covered in as much detail and by as many compatible and relevant techniques as possible. However, it is necessary to be more selective, and the compilation that follows represents some of our own proposals as well as those that have arisen from discussion with colleagues and from within the literature. It must be accepted that this list is of course not comprehensive and that the priorities we have allotted to individual proposals will vary as time and techniques move on.

Having much experience of just how unpredictable the results of geophysical survey may be it is perhaps unwise to prioritise this list. However, it may be helpful to try and we have therefore adopted the following very rough and ready scoring for each proposal, based upon a balance between the practicality of survey and our (more limited) perception of archaeological necessity:

- *** indicates that the survey is well worth attempting, with a reasonable probability of obtaining clear (positive or negative) results,
- ** indicates that a survey is worth attempting, but may result in less clear or more ambiguous results,
- * indicates that a survey might be worth attempting, but is unlikely to be very informative.

STONEHENGE

1 Detailed resistivity profiling (and perhaps GPR) survey of the Ditch and Bank (to refine detail of segmentation and possible entrances around the perimeter of the circles). **

2 Detailed resistivity profiling and GPR of resistivity anomalies A, B and C (to investigate the nature of resistivity anomalies here, in parts of the site which have apparently been excavated). **

3 Detailed resistivity and caesium magnetometry of unexcavated western half of the monument (to search this area for more information on unexcavated features). *

4 Detailed resistivity and caesium magnetometry of the area to the SW of the monument, immediately outside the Ditch (to search for undetected features which may lie on the main monument axis). *

THE AVENUE

1 Re-survey the Avenue, with magnetometry and resistivity, at a narrower sampling interval than previously, from its Stonehenge terminal to a position beyond the elbow (to establish the presence and location of any contemporary features such as pits, post- and stone-holes). The survey should take in at least 60 m of ground to either side of the main alignment. **

2 Magnetometer survey of the remainder of the course of the Avenue, also widely to either side (to identify related features). ***

3 Magnetometer and resistivity survey at West Amesbury (to identify the Avon terminal). **

THE PALISADE

Trace this feature to its full extent (to help establish its overall plan and relationship to neighbouring features). ***

THE CURSUS

Magnetometer survey of the undisturbed sections of the Cursus, and to either side of it (to determine the detailed outline of the ditches and the nature of any contained or impinging features). **

DURRINGTON

1 Magnetometer survey of the environs of Woodhenge, to its south and west (to clarify and add to the evidence from many cropmarks in this area and to search for further features contemporary with the use of Woodhenge and Durrington Walls). ***

2 Extend this survey to surround the Cuckoo Stone, and survey the latter's previous surroundings with resistivity (to explore for structures that may be related to this isolated stone, e.g. a possible long barrow). **

3 Complete magnetometer coverage of the interior of Durrington Walls, and experiment with high resolution survey over known circles (to extend the results of successful existing survey). **

4 Magnetometer survey of the area between Durrington Walls and the Packway Enclosure and (where accessible) the immediate environs of the Packway Enclosure (to extend the identification of Iron Age activity in this area and clarify its relationship with the Durrington Walls enclosure). ***

5 Magnetometer survey of the eastern approach to Durrington Walls from the river Avon (to seek any features linking the watercourse to the henge). *

6 Magnetometer and resistivity survey of any accessible ground near the site of the flint mines located to the north-east of the henge (to locate additional pits and any associated features). **

ROBIN HOOD'S BALL

Magnetometer survey of the causewayed enclosure and its surroundings, inclusive of recently located flint and pottery scatters (to identify details of the enclosure, of outlying activity and of any linkages between them). ***

KING BARROW RIDGE

Extend magnetometer survey from the area of site W59 (to identify further features linked with the surface lithic scatters here, and to plot their extent). ***

NORTH KITE

Magnetometer survey of the entire North Kite and any associated features (to clarify the nature of the North Kite and its immediate associations). **

OTHER LOCATIONS

1 Magnetometer survey of the possible sub-rectangular enclosure (RCHM(E) 1979, 22) located between Stonehenge and Normanton Down barrow group at NGR SU 119 417, a possible Late Bronze Age settlement where fragments of quern have been found (to explore the nature of these traces). ***

2 Magnetometer survey of various other possible enclosures of unknown date and function defined by ditches visible as cropmarks in the World Heritage Site, e.g. near Druid's Lodge in Berwick St James at NGR SU 104/388 and SU 097/392 and on Winterbourne Stoke Down (SU 101/422). ***

3 Magnetometer survey of the multi-period (Neolithic to Late Bronze Age and Roman) landscape south and south-east of Long Barrow Crossroads. The area contains long barrows, a cluster of small round barrows, linear ditches (possibly dating from the Early Bronze Age), field systems, a possible oval enclosure, and surface scatters of Early and Late Bronze Age, Deverel Rimbury and Roman pottery and fragments of querns. A major linear ditch running from Rox Hill to Winterbourne Stoke Crossroads cuts across the fragmentary field systems in the area. A hut settlement of Thorney Down type recorded by Vatcher and Vatcher near the crossroads in 1967 is probably part of the wider landscape of archaeological features in this area. ***

4 Magnetometer survey of the possible Roman settlement near the summit of Rox Hill plus later Bronze Age activity, linear ditches and 'Celtic' field systems (to complement detail from aerial photography in this area). ***

5 Magnetometer survey in Stonehenge Bottom north of the A303/A344 junction (to locate and follow the curving ditch detected by the 1993 GSB survey just south of this junction). **

6 Multi-technique examinations of selected barrows and barrow groups (to determine barrow structure, survival of barrow features and of any features in their vicinity). ***

Conclusions

It has not been an easy task to review such an enormous corpus of extant geophysical data and we have had to skim very lightly over much of it. It has not been much easier to propose ways forward either—despite an abundance of archaeological questions to address, at greatly varying spatial scales. We offer here a somewhat conservative view of the place of geophysics in this landscape: that is, that the greatest benefits are still to be obtained, not necessarily from new or emerging techniques, but by the ever-increasing refinement of those that are already familiar and proven by experience. There is great potential for the development of magnetometry, both to utilise greater sensitivities and also to accelerate the speed of ground coverage. Resistivity should also figure in this process, both allowing much expanded coverage and also exploiting multiprobe methods so as to improve resolution in all three dimensions. Each technique requires careful selection depending on the special demands of individual sites or areas; the more deliberate use of complementary technologies is recommended, and it must be accepted that some modest physical intervention will be repaid by considerable dividends towards the future development both of archaeological and geophysical recording.

Much of the history of archaeological investigation around Stonehenge has, naturally enough, been concerned with studies of individual monuments. The limitations of this 'timid' approach (Bradley 1993, 48) are now widely acknowledged and attention is increasingly being diverted to consideration of the landscape setting within which field monuments are just one manifestation of a diversity of human activities. Geophysical survey, too, has tended in the past to be monument-focused. This will of course continue, but developments taking place now put the methodology at the forefront of landscape exploration, not just of the grander monuments and their groupings and alignments, but of the provocatively empty spaces between.

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ALEX BAYLISS, CHRISTOPHER BRONK RAMSEY and F. GERRY McCORMAC

Dating Stonehenge

As part of the recent research programme on the twentieth-century excavations at Stonehenge (Cleal *et al.* 1995), a series of nearly fifty new radiocarbon determinations was commissioned. A chronological model of the site has been developed which combines the evidence of the radiocarbon measurements with the stratigraphic sequences recovered during excavation. This has enabled much more precise estimates of dates of archaeological interest to be calculated.

A number of points of archaeological and scientific interest have been raised by this programme of work; in particular the importance and complexities of archaeological taphonomy are seen as crucial. Some of the choices which were encountered when building the model are also discussed. Above all this work is seen as both analytical and interpretative, and will inevitably be modified as more data become available, different questions are asked, and different interpretative frameworks adopted.

DAVE BATCHELOR

Mapping the Stonehenge World Heritage Site

This paper describes the work of the Central Archaeology Service in creating an integrated and dynamic database that encompasses geographic and textual data from a number of disparate sources. It will concentrate on the physical and cultural landscape that surrounds Stonehenge rather than the monument itself.

A. DAVID and A. PAYNE

Geophysical surveys within the Stonehenge landscape: a review of past endeavour and future potential

The techniques of archaeological geophysics now have a very widespread currency in British archaeology. Those most commonly in use, magnetometry and resistivity surveying, can be particularly effective for the mapping of the buried outlines of domestic, industrial and funerary sites from later prehistory until the present day. Given the pre-eminent reputation of Stonehenge and its surroundings it is perhaps surprising that such techniques have not been used more exhaustively to explore the area for hidden detail. However, in recent years, fuelled both by research initiatives and the modern pressures now affecting this World Heritage Site, geophysical survey has indeed been applied with increasing determination. This paper provides an overview of this recent work, both at Stonehenge itself and at neighbouring sites, and will confront both its present limitations as well as its future potential.