8

The statistical analysis of ground probing radar data from "radar-weak" sites

Jon Bradley and Mike Fletcher

School of Computing, Staffordshire University

8.1 Introduction

Traditional techniques for the analysis of ground probing radar data, in addition to being extremely time consuming, can often prove inadequate for some types of site. These tend to be those sites which are defined by weakly reflective features such as in-filled ditches and pits, rather than strongly reflective features such as wall foundations, air cavities *etc.* Such sites (referred to hereafter as *radar-weak* sites) exhibit weak (low contrast), complex responses which make it difficult or even impossible for the analyst to identify features with any degree of accuracy.

The nature and extent of the problem facing the analyst can more readily be appreciated by comparison of Figure 8.1 (a radar image from a *radar-strong site*) with Figure 8.2 (a radar image from a radar-weak site).

This paper offers a computational solution to this problem, known as activity analysis (Bradley & Fletcher 1996). This technique not only allows the production of meaningful and useful results from radar-weak sites, but also speeds up the analysis enormously and removes a great deal of the subjectivity from the whole process.

The paper will first briefly describe the basis for and the nature of the techniques used. Their use, in conjunction with time-slicing techniques such as those proposed by Milligan & Atkin (1993) will then be discussed. The application of these techniques to a radar-weak Iron-Age site on the Welsh Borders will be described, and the success of the exercise will be assessed by comparison of the results with those of a resistivity survey carried out on the same area.

8.2 Statistical feature extraction

When a radar analyst sets out to interpret the results of a radar survey, what are they looking for? The answer to this question is not straightforward, and different people might disagree on the details. Obviously the analyst is attempting to pinpoint radar signatures which might correspond to recognisable physical features buried beneath the surface, but how would one go about characterising or describing these signatures? A reasonable definition of a significant feature might perhaps be *a characteristic shape or form, defined by regions of large, coherent change in pixel intensity.* This definition requires a little qualification; the term 'coherent changes' refers to a near-uniform change in intensity of a large, localised group of pixels (*i.e.*, not noise), whilst the term 'characteristic shape' refers to commonly recognised categories of signal shape *e.g.*, planar, hyperbolic *etc.* Of course, not all objects and features will result in easily recognisable signatures. Some will produce weak, complex and therefore hard to interpret signals, and this is where the skill of the analyst (and unfortunately, in some circumstances, the extreme subjectivity of the analysis process) comes into play.

8.2.1 Statistical measures of radar activity

One way round the problem of weak, complex signals and the subjectivity that is introduced into any analysis as a result of them, is to examine not the specific nature of the signal, but rather its statistical properties. Using such techniques it is possible to produce maps of the *radar activity* at each point on the survey site. Such approaches have received little concerted attention in the literature, with one isolated reference to the possibility in the paper by Goodman & Nishimura (1993).

Several different statistical measures have been investigated (Bradley & Fletcher 1996), the most useful being the *sum of square errors (S.S.E.)* of the pixel values in an area of the image. The *S.S.E.* is given by

$$S.S.E. = \frac{\sum_{i=0}^{n} (x_i - \bar{x})^2}{n}$$

where n is the number of pixels in the region, x_i is the intensity of pixel number i and $\bar{x}$ is the local mean pixel intensity $\bar{x} = \sum_{i=0}^{n} x_i \big/ n$.

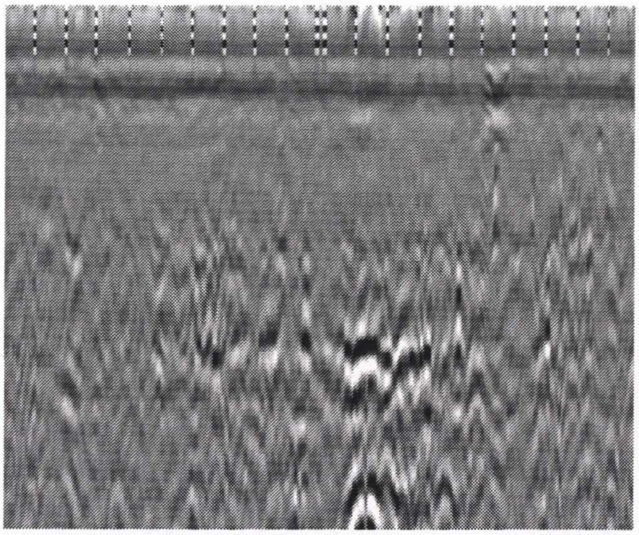

Figure 8.1: A typical radar image from a radar-strong site.

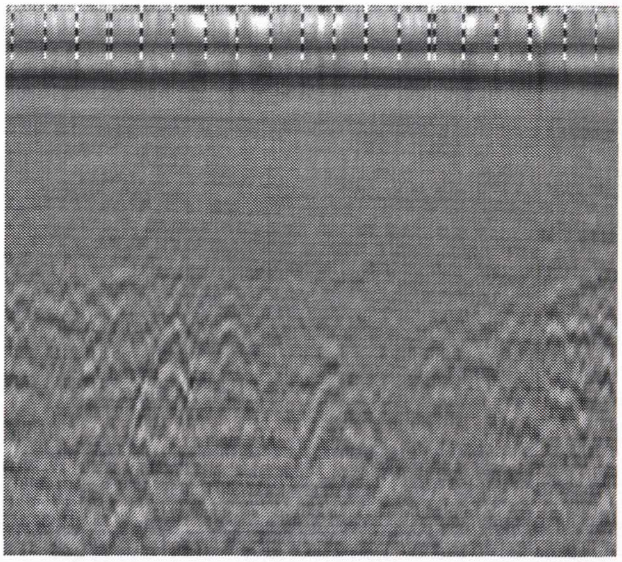

Figure 8.2: A typical radar image from a radar-weak site.

In practice, the *S.S.E.* value is calculated at regular intervals along each radar image over several pixel columns (to reduce the effects of noise). This results in a string of values or *activity profile* for each image. These profiles are then grouped together to form an *activity map*.

8.2.2 Time slicing

Ground probing radar has two main advantages over other geophysical techniques. The first of these is the ability to operate successfully through hard surfaces such as tarmac (not of startling relevance to this study), and the second is the ability to reveal depth information about a site. One must be very careful about speaking of depth in relation to radar studies, as the vertical scale in radar images is in fact a measure of the time taken for a signal to go from antenna to reflector and back (not necessarily a simple function of depth). However on some sites, particularly those which are very homogeneous in nature, such as our class of radar-weak sites, the depth/signal return time equivalence is a reasonable approximation (or as near as one can really expect to get).

This being the case, it would appear reasonable to make use of a technique suggested by Milligan & Atkin (1993) and adopted by Goodman & Nishimura (1993), wherein the radar data for the site is split into a number of horizontal layers or *time-slices*. For each time-slice, it is possible to produce a separate, independent activity-map, and by comparison of these maps it should be possible to draw conclusions related to the depth (or at least *relative depth*) of features on the site.

The whole process, from radar-data to time sliced activity maps, is shown schematically in Figure 8.3.

Although very simple in theory, the combined techniques of activity profiling and time-slicing have proved very successful in practice, as we shall see in the next section.

8.3 The site

The site, designated as Hindwell Enclosure 1, lies within the Walton Basin in the County of Powys (OS Ref. 240 605). It was discovered using aerial photography and forms part of a large complex of such sites currently under investigation by the Clwyd Powys Archaeological Trust (CPAT).

The site itself is located in a large flat field of grass, and was first spotted as a crop mark caused by new clover growth shortly after mowing. A preliminary survey carried out by CPAT revealed that there is no topographical evidence of any archaeological feature — perhaps not surprisingly given the intensively cultivated nature of the area. The only topographical features of any note are the very slight downhill gradient of the field from the north-west to the south-east corner, and the presence of what appears to be a silted up palaeochannel running in a roughly west–east direction, just to the north of the enclosure.

The aerial photographic evidence reveals a roughly rectangular enclosure, 60m by 45m in size, delineated by what appears to be a boundary ditch 2–3m in width. Its long axis is oriented in a WNW–ESE direction, and its western end is slightly broader than its eastern, and has a slightly convex boundary. There is a break in the boundary at the eastern end of its north side (possibly an entrance causeway), and an irregular feature in the north-west corner of its interior (interpreted as evidence of gravel quarrying at some point in time). The topology and crop marks (grey shading) are shown in Figure 8.4, along with the position of the survey grid used. The contour interval is 0.1m and the heights are relative.

Note that radar surveying was carried out over only the main grid (which is 80m × 80m in size), but that resistivity surveying was conducted over the main grid *and* a small 20m × 20m northwards extension at the north-west corner of the grid. This extension was made to include some vague crop-mark features spotted from the ground on a preliminary visit to the site.

8.4 Radar results

Radar surveying of the site was carried out along 1.0m transects in both south–north and west–east directions using a 500MHz antennae. The volume of data produced from the survey was extremely large (approximately 250 MBytes) and a skilled analyst would have taken several weeks to process the data.

Firstly the data was rectified to remove horizontal distortions caused by uneven travel speed of the antennae across the ground. This process took about a day, as it required fairly intensive operator intervention, and produced a set of radar images of standard length. These images were then batch processed to produce time-sliced activity maps, using software developed at Staffordshire University. Each map took approximately five minutes to produce on a DEC-Alpha box (the same software running on a 75MHz Pentium would take approximately eight to ten minutes).

Results are presented here as a series of individual grey-scale maps, one for each time window. Depth measures given are based on a surveyors value for the signal propagation velocity of 0.11m/nSec. It should be stressed that these are *rough* estimates, with an error factor of possibly ±10%. Each activity map covers a range of 10nSec (approximately 0.45m). The results of the radar analysis are quite noisy in nature, with many prominent spikes which tend to spoil the dynamic range of the features of interest. The images in Fig. 8.5 are the results after filtering using a selective de-spiking algorithm based on the local neighbourhood standard deviation of each pixel. The data in the images has been normalised to cover the full range of grey-levels in order to obtain the greatest possible contrast, and an indication of the relative signal strengths is given with each image. A verbal summary of what the authors consider to be significant anomalies is also provided (the subjectivity of this exercise is duly acknowledged, and if readers wish they can ignore this and draw their own conclusions).

The shallowest image (shortest signal return times) covers depths between 0.3m and 0.8m and is fairly homogeneous in nature, *i.e.,* it has a low range of activity values. This can probably be attributed to agricultural activity (*i.e.,* ploughing) which has disturbed the topsoil. Faint signs of the enclosure boundary do show up (particularly in the west), as do signs of the quarry pit.

The boundary of the enclosure is particularly prominent in the second and third activity maps (0.5–1.1m and 0.8–1.4m respectively). It appears as a linear feature of relatively low activity and is particularly well defined in the west, east and south sides of the enclosure (its northern boundary being occluded by the presence of the quarry pit, which appears as a very obvious region of anomalously low activity at this level). The boundary ditch becomes less obvious at greater depths, fading out almost entirely by the fifth activity time slice (1.4–1.9m), making it possible to estimate maximum boundary ditch depths of about 1.9m.

Careful examination of the south-eastern corner of the enclosure just inside the eastern boundary ditch on the first and second maps, reveals the presence of a faint line of low activity (A) running parallel to the eastern ditch at a distance of approximately 5m from it. The feature is shallow and linear, but very faint, and may represent traces of an internal ditch or line of pits extending to approximately 1m below the current ground surface.

By the sixth activity map the enclosure has vanished entirely, leaving only the low activity anomaly of the quarry, which begins to show signs of fading into the background, thus indicating a depth of approximately 2.0–2.2m.

8.5 Verification of results

The radar results (Fig. 8.5) are in themselves quite impressive. The more obvious features such as the boundary ditch and quarry pit are so readily apparent that they probably do not need independent verification. However there are a number of other features — notably the internal feature at the eastern end of the enclosure — which can by no means be said to be 'definitely real'. In order to demonstrate (or refute) the sensitivity of the technique of activity mapping, it is necessary to seek confirmatory evidence of the presence of these features.

A means of assessing the performance of the activity analysis system was available in this case — the resistivity survey of the site carried out at the same time as the radar survey. The resistivity survey was carried out over the whole survey area (including extension) at 1.0m intervals. A grey-scale map of the resistivity survey results is shown in Fig. 8.6. White represents areas of high resistivity, black areas of low.

The most obvious feature of note is the boundary of the enclosure. This shows up beautifully as a low resistivity feature between two and three metres in width, with a clear gap of approximately four metres at the eastern end of the northern boundary. The position and dimensions of the ditch match closely those revealed by the radar survey. What is not present in the resistivity data is any indication of the depth

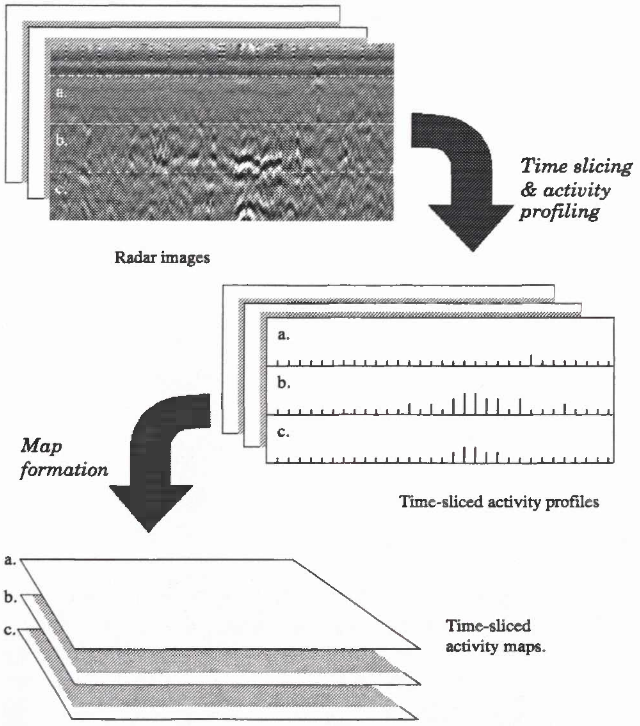

Figure 8.3: The activity analysis process.

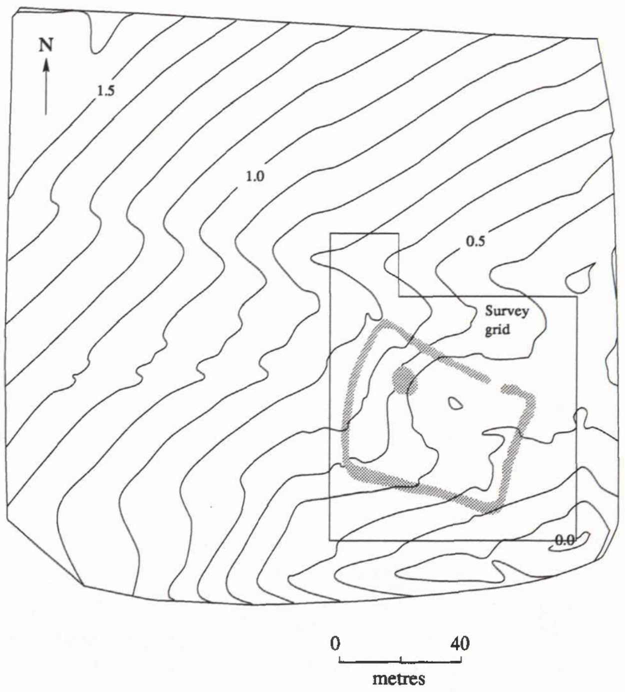

Figure 8.4: Topographical and crop-mark evidence at Hindwell Enclosure 1.

of the ditch. The gravel workings show up clearly in the resistivity data, covering an irregular area of approximately 25m × 25m. The discrepancy in area between resistivity and crop mark data (where the workings appeared to cover an area of only 10m × 10m) is not fully understood, although it can be seen that the crop-mark corresponds nicely to a westward extension of the workings (a) into the highly resistive area (b). Again the resistivity data has nothing to say on the subject of depth. The northern edge of the gravel workings merges into the low resistivity anomaly of the ditch. This would suggest (perhaps unsurprisingly) that the two are unlikely to be contemporaneous.

The site as a whole appears to have an overall trend in resistivity from generally high in the north-west corner of the survey, to low in the south-east corner. This could reflect drainage patterns in the field, which slopes very gently down to the south-east and which would therefore be expected to be damper (and therefore less resistive) in that corner. In the 20m extension to the survey, a very strong, linear feature of low resistivity, approximately 8–10m wide, runs in an east–west direction. A subsidiary branch of the feature runs southwards for about 5m, and the whole appears to correspond physically with the palaeochannel mentioned in section 8.3. The palaeochannel (even in its silted state), would tend to provide extra drainage to the north-western corner of the site, and its presence would therefore enhance the generally high resistivity at this point.

Turning now to the interior of the enclosure, even a cursory examination of Figure 8.6 will reveal the presence of a linear feature of low resistivity running parallel to the eastern ditch of the enclosure. The feature starts at the southern boundary ditch, is about 30m in length, 1–2m wide, and is set in about 4m from the edge of the eastern boundary ditch. What this feature represents is not known, although it is certainly not natural. The presence of this feature in the resistivity data confirms, in a very positive way, the sensitivity of the radar activity mapping technique.

If large scale trends due to drainage patterns are removed from the resistivity data by high pass filtering, features which are *not* found in the radar data are brought to light. In Figure 8.7, the filtered resistivity data is displayed as an artificially lit surface, which looks rather like an aerial photograph of a 'shadow site' seen in the late evening (*cf.* Scollar *et al.* 1990, pp. 33–77, for details of Crawford's site classification scheme).

The reason for displaying the data in this way is that low-definition features can often be picked out under such conditions. The main point of interest that comes to light in this exercise is a second linear feature inside the enclosure. This feature runs parallel to the first, about 10m from it and starts at the southern ditch. It is poorly defined, about 1m in width, and is shorter than the first at about 15m in length. Again its nature and function are not known, but the regular appearance and relationships between the two linear features and the enclosure boundary do perhaps suggest internal structures of some description. This is

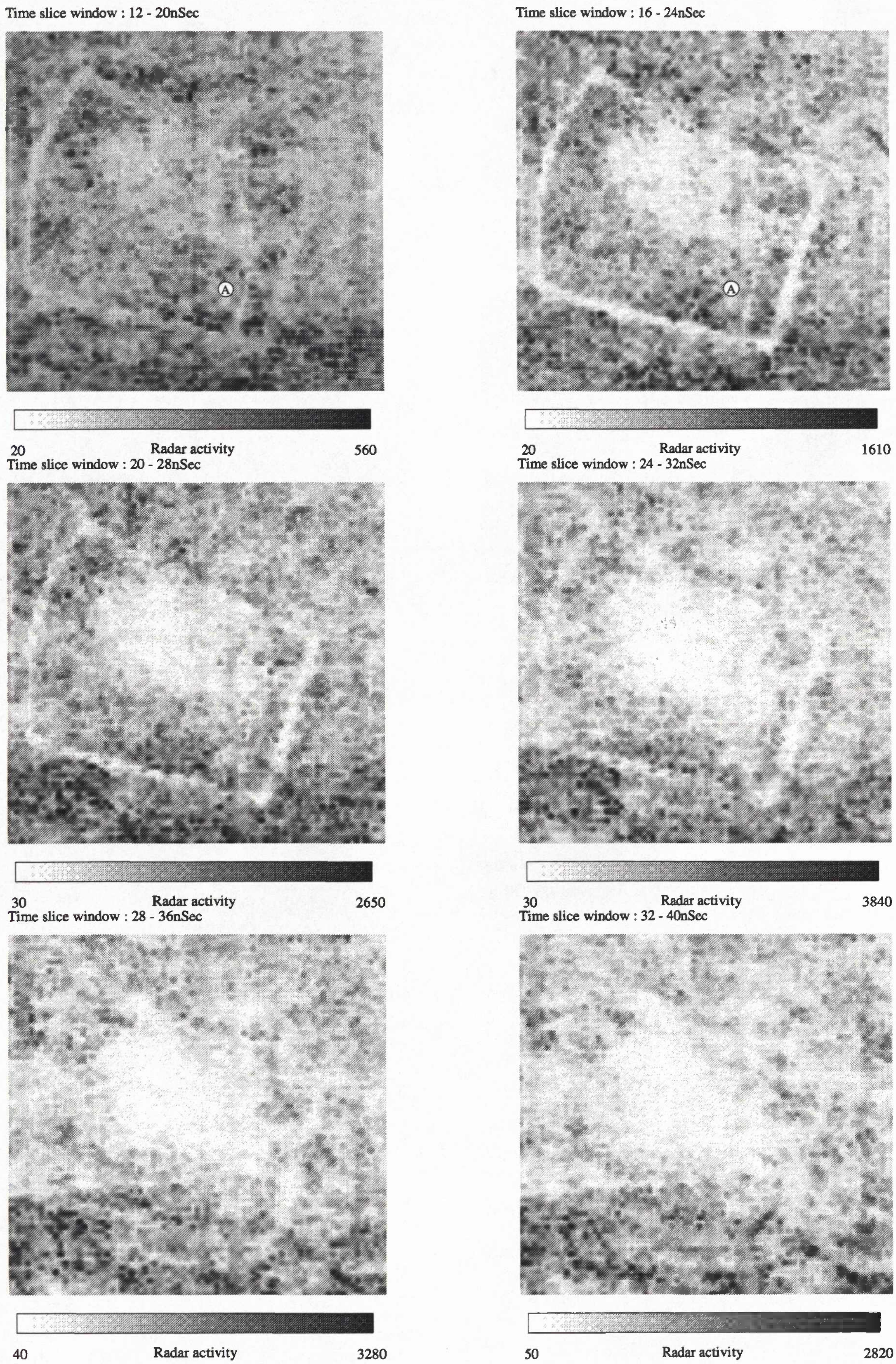

Figure 8.5: Radar activity maps for a series of signal return time windows

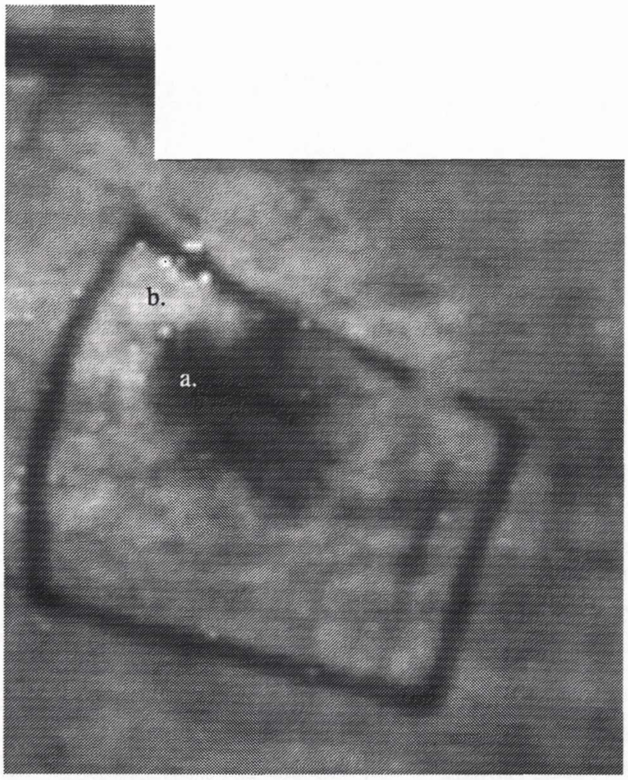

Figure 8.6: The resistivity results for Hindwell 1

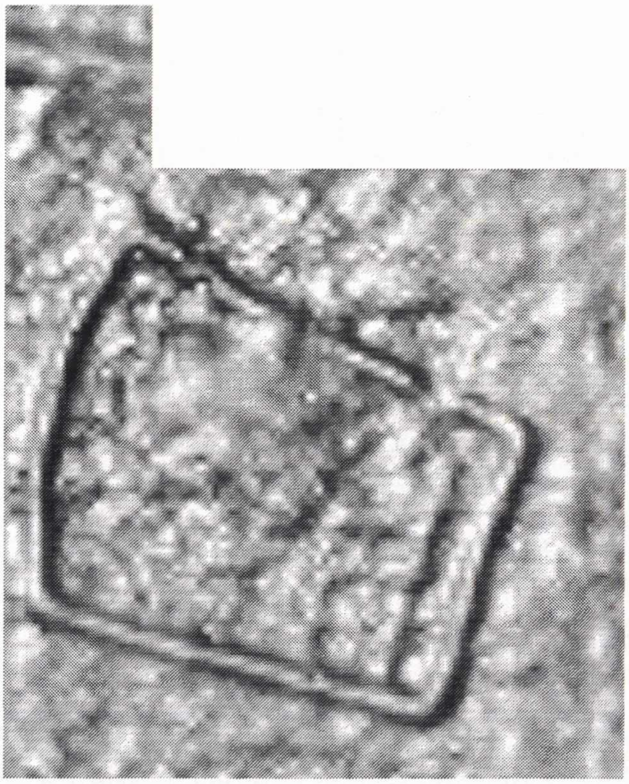

Figure 8.7: Resistivity residuals at Hindwell 1.

clearly a case where the resistivity technique betters the radar surveying technique.

8.6 Conclusions and further work

Activity analysis, a statistical technique which allows the automated treatment of ground probing radar data, has been described and its performance demonstrated by use on a survey of an Iron-Age site in the Walton Basin. The case study used is a radar-weak site with very low levels of radar activity throughout — basically a difficult target for ground probing radar work. The results of the radar survey are to a large extent confirmed by the resistivity survey. It is important to note that whilst the results of the radar surveying are perhaps not as convincing as those of resistivity surveying, the claim is *not* that activity analysis allows radar to replace resistivity surveying, but that *if* radar surveying *is* to be used, the results that it produces (particularly in the case of radar-weak sites) can be appreciably enhanced by use of activity analysis.

To summarise, activity analysis of radar data confers several advantages over conventional analysis techniques, particularly on radar-weak sites:

Objectivity The technique removes the need for subjective decisions from the process of data-analysis. This means that all subjectivity is postponed until the interpretation stage.

Speed Activity analysis allows large volumes of radar data to be analysed *in more detail* in a small fraction of the time that manual analysis by a skilled radar analyst would take. This increase in speed means that a more in-depth study, possibly using the time-slicing techniques described, can be carried out.

Accuracy Particularly on large surveys, where an analyst would get tired and make mistakes, the activity analysis will maintain a consistent level of performance for an indefinite period.

Sensitivity Activity analysis is capable of revealing a wealth of detail that may not be readily apparent to traditional analysis techniques.

References

BRADLEY, J. & M. FLETCHER 1996. 'Extraction and visualisation of information from ground penetrating radar surveys.' *In* H. Kamermans & K. Fennema (eds.), *Computer Applications and Quantitative Methods in Archaeology CAA95*, pp. 103–110. Institute of Prehistory, University of Leiden, Leiden. Analecta Praehistorica Leidensia 28.

GOODMAN, D. & Y. NISHIMURA 1993. 'A ground-radar view of Japanese burial mounds.' *Antiquity* 67: 349–354.

Milligan, R. & M. Atkin 1993. 'The use of ground-probing radar within a digital environment on archaeological sites.' *In* J. Andresen, T. Madsen & I. Scollar (eds.), *Computer Applications and Quantitative Methods in Archaeology 1992*, pp. 21–32. Aarhus University Press, Aarhus.

Scollar, I., A. Tabbagh, A. Hesse & I. Herzog 1990. *Archaeological Prospecting and Remote Sensing.* Cambridge University Press, Cambridge.

Jon Bradley
School of Computing
Staffordshire University
Beaconside
Stafford UK

`J.Bradley@soc.staffs.ac.uk`

Mike Fletcher
School of Computing
Staffordshire University
Leek Road
Stoke-on-Trent UK

`M.Fletcher@soc.staffs.ac.uk`