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Impact of Resolution on the Interpretation of Archaeological Prospection Data

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Abstract

Geophysical surveys are widely used for archaeological prospection. As interpretation of results depends on the quality of obtained data, the influence of spatial resolution has to be investigated. Strategies are deduced from sampling theory to resolve anomalies associated with archaeological features. A comparison of various field surveys with different grid dimensions demonstrates the importance of sufficiently dense data recording.

Introduction

Any excavation of archaeological sites will destroy the buried features under investigation. In addition, the threat to buried archaeological features is ever increasing (e.g. by extensive building and development schemes). Therefore, non-destructive and effective techniques are essential for the evaluation of buried ancient remains. Due to the ongoing development of lightweight and robust field-instruments geophysical methods are nowadays widely used for such archaeological prospection. Data can be analysed so as to direct excavations towards focal points of archaeological interest thus minimising the costs, time and damage while retaining a maximum of information. Likewise, a thorough geophysical survey may yield sufficient information to leave a site intact and preserve it for the future. The rapid cover of large areas aids the recognition of buried archaeological sites in advance of major building schemes and thus facilitates the preservation or rescue of the national heritage.

However, all this depends crucially on the extraction of archaeologically relevant information from geophysical data. Currently data are either displayed as a grey-scale image onto which a skilled interpreter can then draw the location of buried features, or it is subjected to extensive mathematical inversion schemes that may suffer from the underlying ill-conditioned geophysical problems and are very demanding and time consuming in terms of computing power: “[with the final inversion system] it should be possible to process data as rapidly as it can be produced from the field survey [i.e. within days]” (Allum *et al.* 1995).

In what ever way the interpretation is done it will depend on the quality of recorded data. Only if field data are collected in accordance with the *expected* size and nature of archaeological features can a reliable interpretation of geophysical data be achieved. Therefore, *a priori* knowledge of the site is required to adjust geophysical surveys as necessary. However, since such *a priori* knowledge is often very difficult to obtain one must generally aim for a high quality of collected data.

The issue of data quality from geophysical surveys has various aspects. It is important to measure the investigated geophysical properties (e.g. ground resistivity or the earth’s magnetic field) as accurately as feasible, taking natural limitations into account. It is, therefore, of great importance that the chosen techniques match the archaeological, geological and environmental conditions of a site (see e.g. Clark 1990; 124). For each chosen technique the design of instruments has to be carefully adjusted to record data with appropriate precision. For example, Scollar *et al.* (1990; 440) discussed the magnetic noise that arises on archaeological sites. This has direct implications for the choice of sensitivity at which a magnetometer shall be operated. Another aspect of data quality arises directly from the nature of the investigated subject. For buried archaeological features spatial information is of great importance and hence the location of each measurement has to be recorded precisely. Sampling strategies have been investigated for random measurement positions. This work concentrates on data that have been recorded on regular grids, consisting of lines with equally spaced recording stations. The implications of grid dimensions (inter-line spacing and station separation) will be discussed. Relevant archaeological features may be missed or misinterpreted if inappropriate grid dimensions are chosen. The first section will summarise the relevant parts of sampling theory while the second section will demonstrate the importance of high spatial resolution for selected field surveys. This can be seen as a contribution towards the discussion about best field practice that was initiated by the publication of guidelines by English Heritage. It is stated that for magnetometry surveys "... the maximum acceptable separation between instrument readings is 1.0m x 0.5m ..." while for resistivity surveys "... the reading interval is standard at 1.0m x 1.0m ..." (David 1995; 18&27).

Sampling theory

In order to estimate the necessary spatial resolution for geophysical surveys, information about the shape of typical anomalies is required. Figure 1a shows the magnetic anomalies of a buried cube (1m × 1m × 1m) as measured with a fluxgate gradiometer in Britain, traversing South to North. Each trace represents a different burial depth, starting at 0.25m (biggest anomaly) and increasing for each trace by 0.25m. The dependence of the peak width from the burial depth is shown in figure 1b for cubes of different sizes (side length 0.5m, 1m and 2m, respectively). It can be seen that the width as measured at half the peak height (□) as well as the width defined by the separation of southern and northern zero-crossing (Δ) are linear functions of the depth. Archaeological features are mainly buried at shallow depths for which the half-width is approximately given by the size of the cube (Width/Size ≈ 1, see figure 1b) while the zero-width can be estimated as twice the size (fig. 1b).

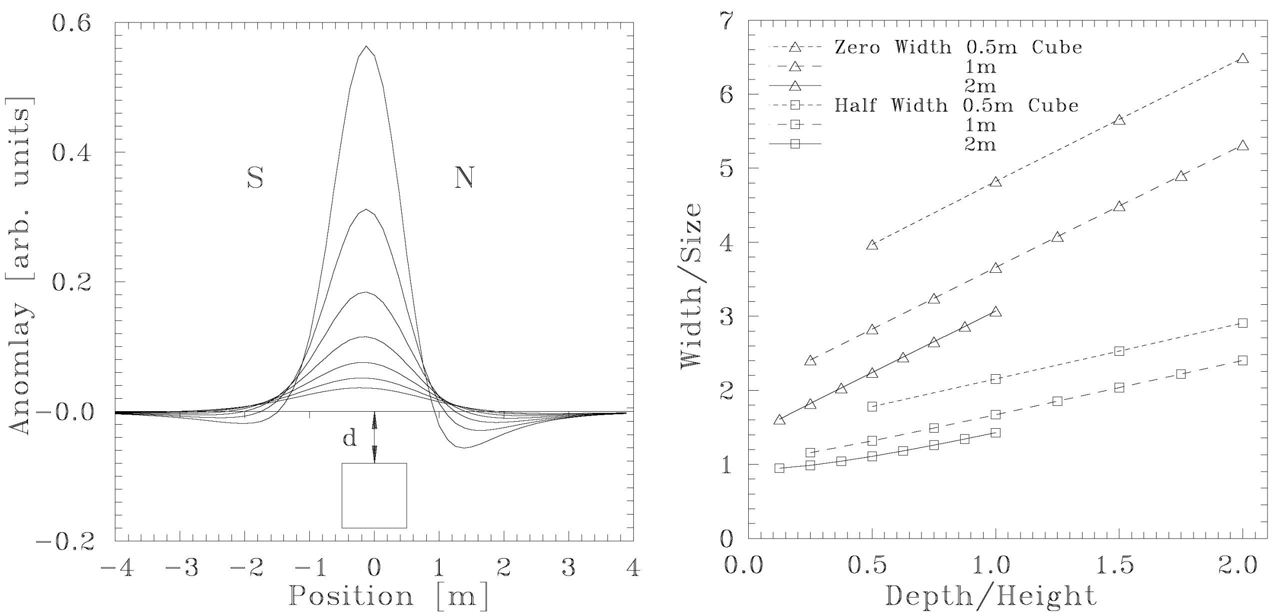

Figure 1: (a) Magnetic anomalies of a cube buried at different depths, starting at 0.25m and increasing for each trace by 0.25m. (b) Width of anomalies vs. burial depth for cubes with side lengths of 0.5m, 1m and 2m. Width and depth are given in units of the respective cube size.

A rough estimate for the required sampling interval can be derived from a probabilistic approach (Florsch & Hulot 1995 and *pers. commun.*). It is based on the probability to "hit" the anomaly of a buried feature with a single measurement. Assuming that a single measurement, recorded between the southern and northern zero crossing (i.e. within the zero-width w_Z), can still be associated with the anomaly (which may in practise be very difficult) the probability p_{hit} for "hitting" the anomaly with a survey grid of spacing a is given by

$$p_{\text{hit}} = \frac{\pi \cdot w_Z^{\;2}}{4 \cdot a^2} \;.$$

This probability is also referred to as "search effort" (Kyrala 1964). For the investigated cube ($w_Z \approx 2 \times$ size, see figure 1b) the anomaly will be "hit" by any grid with a spacing smaller than 1.8 times the size of the buried object. Neither the condition of "hitting" the anomaly with only one reading nor the identification of an anomaly through a value that is recorded close to a zero crossing are suitable for a reasonable interpretation of a magnetometer survey. Therefore, this estimate should only be regarded as an upper limit.

A better estimate can be derived using the so called "sampling theorem". Given a physical property (e.g. the earth's magnetic field) that varies continuously in space, the sampling theorem states that the continuous change can be recovered from discrete readings (e.g. taken at grid stations) if the separation of readings does not exceed the Nyquist wavelength $\lambda_N = ½\lambda_{min}$ (Press *et al.* 1992; 500). Here λ_{min} is the smallest wavelength to be found in the spectrum of the continuous data.

If only the position of the peak is sought for an anomaly the half-width of the peak ($w_h \approx$ size, see figure 1b) can be regarded as upper limit for $½\lambda_{min}$ (the top of the peak is considered to approximate a "half sine wave"). The sampling rate may, therefore, not exceed the size of the objects under investigation. However, it is desirable not only to recover the peak of an anomaly but to have some information about its shape. It has been shown (Schmidt & Sheen 1995) that the power spectrum of gradiometer data can be described as $F(\lambda) \propto \exp(-\,\text{depth} \cdot 2\pi / \lambda)$ where λ is the wavelength. It can then be calculated that for the recovery of the spectral component that contributes 4.3% of the maximal component the sampling rate may not be bigger than the depth at which the feature is buried.

As a "rule-of-thumb" it may, therefore, be concluded that the sampling interval should neither exceed the size nor the depth of expected features. Since the dept is often given by the topsoil thickness (ca. 0.3m) a sampling interval of 0.5m × 0.5m may be recommended. It is worth noting that these values were derived from the information content of recorded data. Hence, image processing ("filtering") can not overcome these limitations.

Field data

The implications of sampling theory, as outlined in the previous section, are best understood by investigating data from field surveys. Geophysical measurements have been recorded with a Geoscan FM18 fluxgate gradiometer and an RM4/DL10 resistivity meter connected to a 0.5m twin-probe frame. These instruments are commonly used for field surveys and are recommended by English Heritage (David 1995; 17&27). However, a smaller sampling interval of 0.5m × 0.5m was chosen (the enclosure at Temple Guiting, fig. 4, was indeed sampled at 0.25m × 0.25m). Magnetometer measurements have been recorded with the instrument stationary, i.e. not walking. From these recorded data subsets at wider intervals have been extracted for comparison. All data were displayed using the *Contors* computer program (Cheetham *et al.* 1989) with bi-cubic interpolation between recorded readings and without further data treatment (e.g. no filtering). All surveys are aligned such that North is at the top of the display.

At Hazleton, Gloucestershire, two middle Neolithic chambered tombs (long barrows) have been found and partially excavated (Saville 1990). A 0.5m × 0.5m resistivity survey was carried out over the nearly undisturbed southern mound. Figure 2a shows the results, indicating kidney shaped quarries at the NE and SW of the barrow as well as a chamber in the middle (dark area). A narrow semi-circular feature crosses the mound in the North. It coincides with the boundary of a grassy area and is probably related to modern ploughing. Of great interest is the rectangular structure at the NW of the mound indicating a forecourt. This is a clear indication of human activity connected with the burial mound. The important archaeological implications of this find will be published elsewhere. A comparison with data from a 1m × 1m grid (fig. 2b) is very instructive. While bigger features (e.g. the quarries and the chamber) are still visible, the plough marks and the forecourt can not be resolved. This clearly demonstrates how a coarse sampling strategy may miss archaeologically relevant features. The survey in figure 2b does not even indicate that parts of the site should be investigated with closer station spacing.

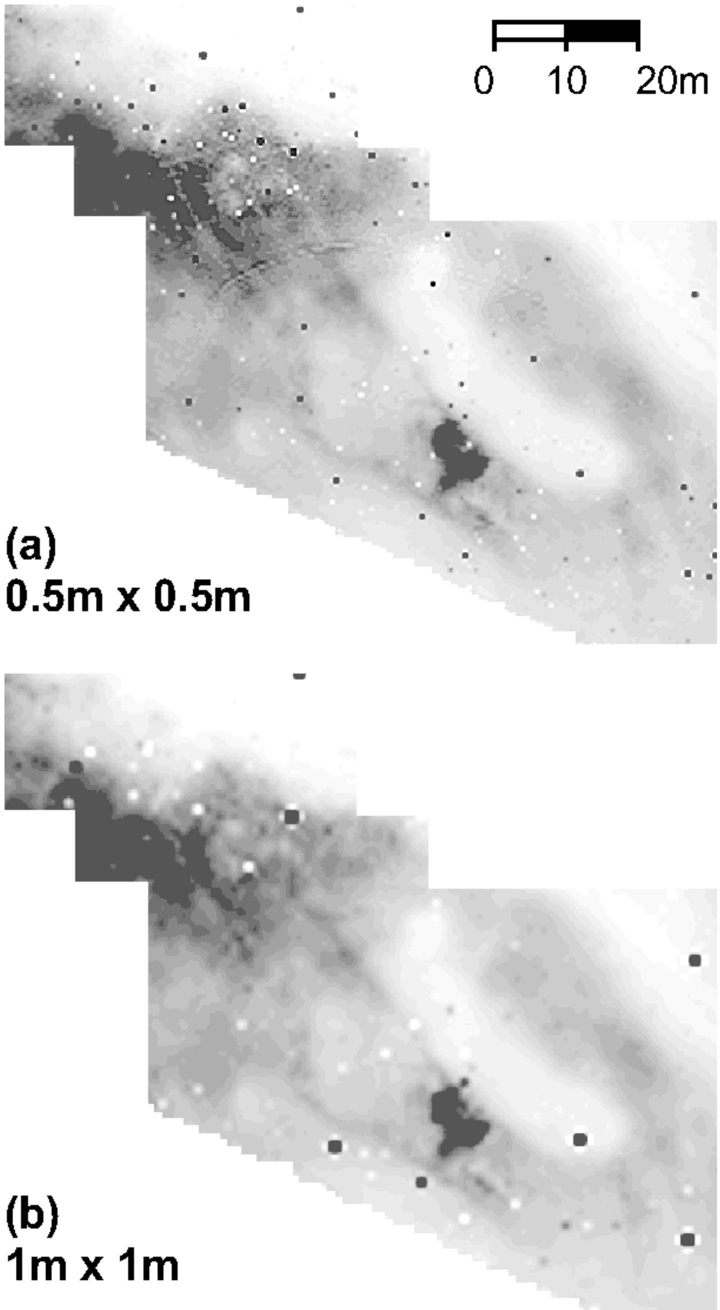

Figure 2: Hazleton South, Gloucestershire, resistivity survey of long barrow; display range 25Ω to 75Ω.

Similar conclusions can be drawn from the magnetometer survey of a mid Iron Age enclosed farmstead at Guiting Power, Gloucestershire (The Park, fig. 3). Obviously, the high resolution data (0.5m × 0.5m, fig. 3a) are much crisper than the coarser data (1m × 1m, fig. 3b). This assists in the archaeological interpretation of the site since features can be identified more easily. In addition, certain features are missing in the coarser survey (e.g. the linear feature running SE in the southern part, fig. 3a[1], a rectangular feature east of the main ditch, fig. 3a[2] and a curved feature in the NW part, fig. 3a[3]). For the archaeological assessment of the site as a whole this additional information may well be of importance.

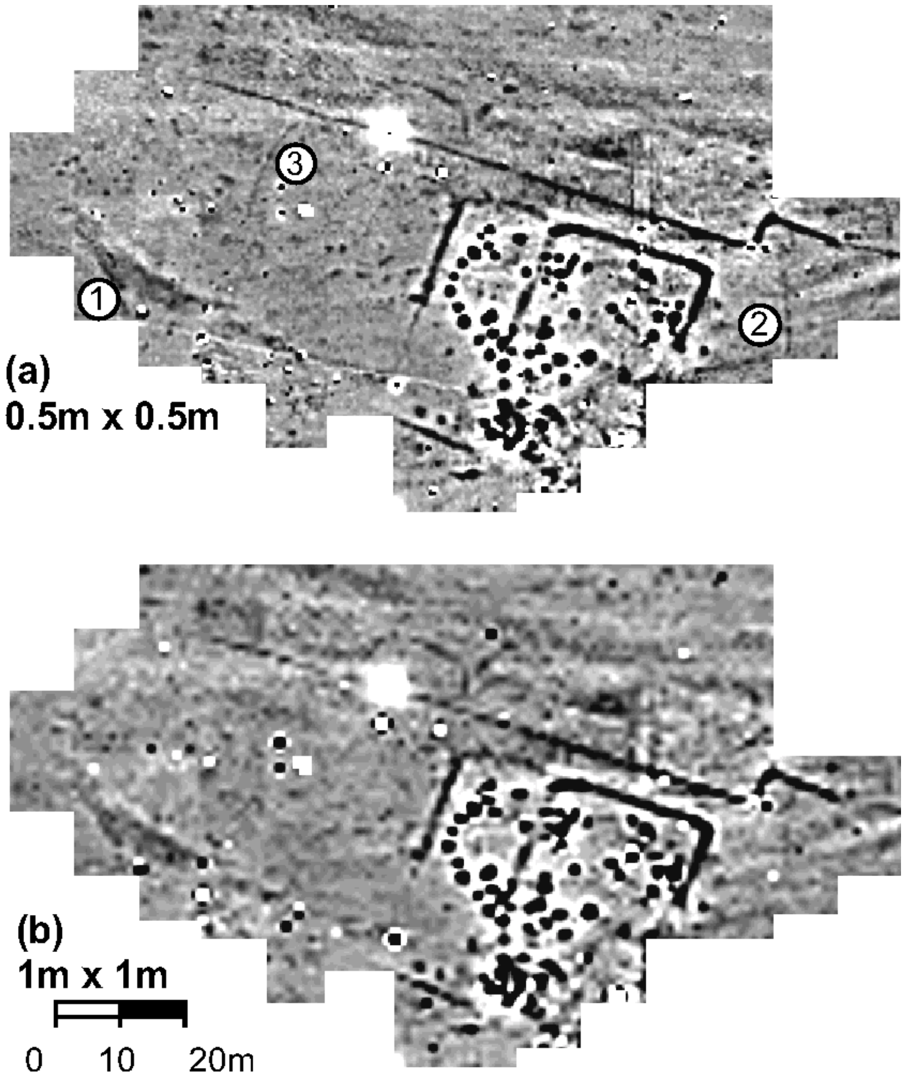

Figure 3: The Park, Guiting Power, Gloucestershire, magnetometry survey of iron age enclosed farmstead; display range -3nT to 3nT. Numbers refer to features mentioned in the text.

The interior of an Iron Age ditched enclosure at Middle Ground, Temple Guiting, Gloucestershire (fig. 4), was surveyed with a gradiometer at 0.25m × 0.25m intervals (fig. 4a). The whole site was additionally surveyed at 0.5m × 0.5m (fig. 4c). Comparing this with data from a 1m × 1m grid it is clear that only at a resolution of 0.5m × 0.5m can the pits in the middle and SE be undoubtedly identified as such. The highest resolution (0.25m × 0.25m, fig. 4a) reveals further features that can otherwise not be seen (e.g. linear feature connecting pits, fig. 4a[1]). For this survey the effect of non-isotropic sampling was investigated (0.25m × 1m, fig. 4b). Operating a Geoscan fluxgate gradiometer in its “walking mode” allows to retain an inter-line spacing of 1m while taking samples at station separations of only 0.25m. This is recommended by English Heritage (David 1995; 18) since survey speed and high resolution - at least in one direction - can be combined. In figure 4b the outcome of such survey was *simulated* with data extracted from the original survey, using a linear interpolation between adjacent lines (this can be improved by using more sophisticated schemes like bi-cubic spline interpolation). A comparison shows that the result is much more like the 1m × 1m survey (fig. 4d) than the 0.25m × 0.25m survey (fig. 4a). Even the data recorded at 0.5m × 0.5m (fig. 4c) are better defined. Data recorded under the recommended field conditions (i.e. recording while walking instead of stationary measurements as in figure 4) will suffer from poorer positioning accuracy and will, therefore, show worse results.

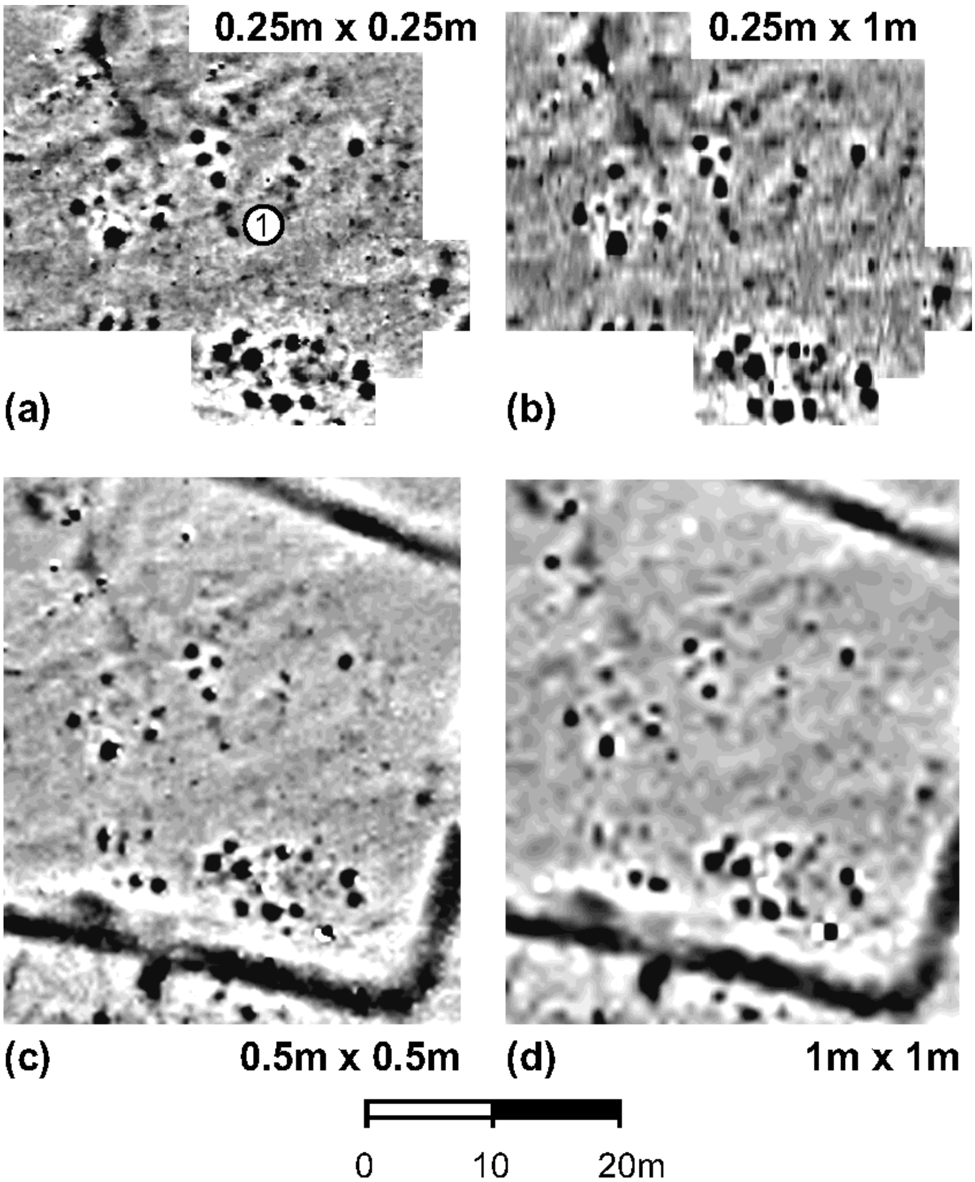

Figure 4: Middle Ground, Temple Guiting, Gloucestershire, magnetometry survey of iron age enclosure; display range -3nT to 3nT. The number refers to a feature mentioned in the text.

At a site of an Iron Age ditched enclosure near Guiting Power, Gloucestershire (The Bowsings, fig. 5), an area was subjected to repeated magnetic measurements under various recording and surveying conditions (fig. 5a to 5e). While figures 5a, 5b and 5c were recorded with 0.5m × 0.5m station separation, figures 5d and 5e were measured at 1m × 1m intervals. For figure 5a 64 readings were averaged by the instrument at each position to obtain a measurement while for figures 5b to 5e only one reading was taken into account. For figures 5c and 5e data were recorded while walking along the lines. It can be seen that the data measured with the highest effort (fig 5a; 0.5m × 0.5m, average of 64 readings, stationary recording) show the tentative hut circle in the NW corner most clearly. It is interesting to note that the change of station separation (fig. 5a to 5c vs. 5d and 5e) has a much greater influence on data quality than any change of the recording technique (fig. 5a to 5c).

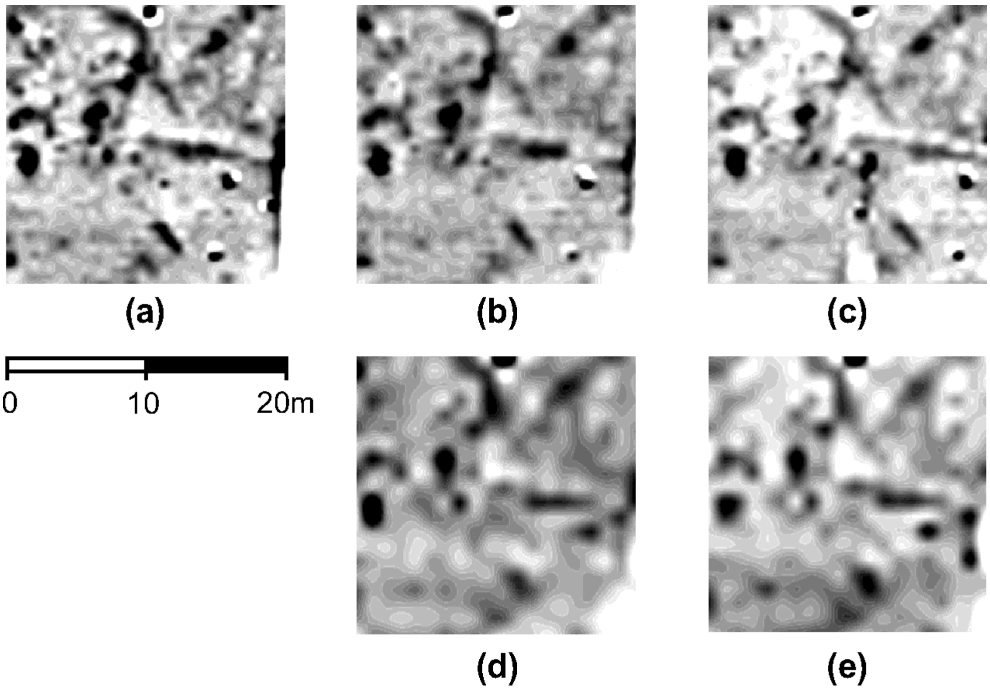

Figure 5: The Bowsings, Guiting Power, Gloucestershire, part of magnetometry survey of iron age enclosure; display range -3nT to 3nT. (a) to (c) were measured with 0.5m × 0.5m station separation, (d) and (e) at 1m × 1m separation. For (a) 64 readings were averaged at each position; for (b) and (d) only single readings were taken; (c) and (e) were recorded while walking.

Conclusion

It was shown that high spatial resolution is of great importance for the quality of geophysical survey data. This can be seen from a theoretical point of view considering the information content of discretely sampled data as well as from a practical point of view comparing survey results obtained at different sampling intervals. It is obvious that mathematical inversion schemes work better if data quality is high. For manual interpretation, however, it may be argued that a skilled interpreter may be able to cope with data that have been recorded on a coarse grid. It was demonstrated in this article that coarse sampling, although revealing wide ditches and massive foundations, may miss other features important for archaeological interpretation. It is often assumed that a fast and coarse sampling may indicate areas of interest for subsequent measurements at closer intervals. Survey results from Hazleton (fig. 2) showed that this is not necessarily the case - the important forecourt would have been missed by a 1m × 1m survey without any such indication.

It should also be noted that archaeological features can often be detected due to their spatial extension. A linear sequence of high or low readings may suggest a ditch or foundation while a patch of distinct readings may indicate an assembly of pits. In order to clarify such structures sufficient spatially related measurements are required. A single reading for a feature is not enough.

Obviously, the demand for high spatial resolution conflicts with the time pressure under which many surveys have to be carried out. Therefore, the trade-off between survey effort and possible archaeological interpretation has to be considered carefully. There may be cases in which the coverage of a large area seems to be of greater significance than a high spatial resolution. However, it is important to be aware of the serious consequences a coarse sampling may have for the analysis of a site. Solutions may be expected from improved instrumentation. With a recently introduced multiplexing system for Geoscan resistivity instruments several adjacent measurements can be recorded at a time. The successful use of arrays of five fluxgate gradiometers with a separation of 0.2m has been reported by Panitzki *et al.* (1995). This indicates that more high resolution data may be available in the future that were still recorded with a good survey rate.

Acknowledgements

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