Dingwall, L., S. Exon, V. Gaffney, S. Laflin and M. van Leusen (eds.) 1999. Archaeology in the Age of the Internet. CAA97. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 25th Anniversary Conference, University of Birmingham, April 1997 (BAR International Series 750, CD-ROM). Archaeopress, Oxford.

Mud and Old Bullets: Geophysical and Behavioural Anomalies in Adverse Environmental and Climatic Conditions — a Case Study in the Use of Stratified Systematic Unaligned Sampling at Merv, Türkmenistan

Stephen Bullas

Abstract

Although successfully pioneered some 20 years ago in the research of geographic settlement patterns, Stratified Systematic Unaligned Sampling (SSUS) has proved slow to be adopted as a sampling methodology in archaeological prospection. The 1996 season at Merv, Türkmenistan, presented a planned opportunity to realise the technique under controlled conditions in the intra-site comparison of industrial debris resulting from Early Islamic metalworking. The primary aim of the survey was to confirm or deny the hypothesis of a specialised industrial site and, if confirmed, to ascertain its approximate extent. A secondary aim of the survey was to conduct research into whether or not unfired mud bricks (in sufficient quantities) - lying shallow beneath the surface on beds of the alluvial clay from which they were made - could be detected by magnetic means. The views of a number of archaeological geophysicists working in Central Asia, North Africa, the United States and Europe were sought before the season started and the results of the various surveys undertaken using susceptibility and gradiometry are presented in this paper. Finally, a comparison of this year's results is made with previous years' resistivity and remote sensing (SPOT) surveys.

1 Geographic and historic contexts

Türkmenistan is situated on the shores of the Caspian Sea, bordered by Iran and Afghanistan to the south and the east and by Kazakhstan and Uzbekistan to the north. Previously part of the Soviet Union, it has been an independent central Asian republic since 1991. Approximately half of its population is centred around the larger towns and cities to the south of the country, of which Ashgabat is the present-day capital. Some 80% of the country is classed as desert or semi-desert.

The ancient cities of the Merv oasis lie in an archaeological park of more than ten square kilometres, approximately 400km due east of Ashgabat — an inland journey of some six hours along the foothills of the Kopet Dagh mountains, through the Tejend oasis and then north for another half-hour past the modern-day town of Mary, which derives its name from that of the ancient sites.

For well over two thousand years, the three cities which grew up along the Merv oasis at the edge of the Kara Kum desert controlled the ancient Silk Road from China through Tashkent and Samarkand and on to the West. During its long history, Merv became one of the most important capitals of Islam and its influence and power stretched from the Oxus through to the Mediterranean. At its height, it occupied an area of some six and a half square kilometres, serviced by and supporting a population in excess of one million inhabitants. Not only was it a strategically placed stronghold of significant commercial importance, it was also an acknowledged centre of religious and secular learning, boasting one of the largest and most important libraries of the early mediaeval period, surviving until the Mongol invasion by Genghis Khan and his followers in 1221. Recent archaeological research has demonstrated that life carried on after this invasion and once again Merv grew in stature in the subsequent centuries, although never managing to reach the zenith of its earlier periods. In its recent past, the site has been used for tank and other artillery practice by the now-departed Russian army, leaving an unknown amount of (hopefully expended) shells and their cases to be found by the magnetometer. Today, visitors to Merv are confronted with an intriguing mixture of partly surviving city walls enclosing a windswept, desolate plain, broken only by the occasional standing monument of unusually grandiose proportions.

2 Environment and climate

Although its people are generally friendly and good-natured, Türkmenistan is an extremely poor country both economically and in terms of any ability to provide many of the every-day items that are normally taken for granted, even in Central Asia. Once outside of the main towns, it proves a daunting task to acquire basic items such as film, batteries and other similar goods on which much of the expedition's equipment depends. In the event of equipment malfunction, there is little hope of effecting repair.

Additionally, there is a massive and disproportionate amount of bureaucracy to be overcome when dealing with anything that impinges on the government — as all archaeological expeditions frequently have a habit of doing, whether intentionally or out of sheer need.

For these reasons, much of the less costly equipment taken on the expedition was duplicated and, although this resulted in a heavy burden of excess baggage, none of it proved to be redundant. In particular, the combination of temperature extremes (35ºC by day, often around freezing-point by night) and the all-pervasive desert sand caused at least one item of equipment to malfunction each day. Among the casualties were exploding batteries, musical magnetometers and thunderstruck susceptibility meters. Clearly, none of the PC laptops could be risked out on site, which meant that much time was wasted on the manual execution of normally automated tasks and that none of the results could be processed in real-time.

Adding to the concerns was the rapidly deteriorating political situation over the nearby border with Afghanistan, from whence Islamic fundamentalism in the form of the Taliban army was anticipated at any moment. It is a matter of record that in the preceding four years, one team member had died in the desert of a heart attack brought on by heat exhaustion and that another member of the team had been shot at on-site by a rifle bullet.

3 The International Merv Project, its aims and objectives

The IMP is a collaboration between British, Russian and Türkman scholars encompassing one of the largest, fully-integrated, multi-disciplinary archaeological expeditions currently working in Central Asia. To date, five years of excavation have taken place and a further season is presently being planned for 1997.

Amongst the Project's aims are the mapping, recording and re-assessment of the cities of Merv by local and remote sensing (satellite, airborne and non-intrusive geophysics) as well as by archaeological excavation. During the 1996 season, the objectives of the geophysical survey were as follows:

1. to ascertain, as far as possible, the physical extents of the supposed Early Islamic 'industrial area', to determine the foci of hitherto unlocated metal workings and to attempt to establish any patterns of distribution in the layout of the various kilns and furnaces; success in this latter task would then be considered for providing some of the possible parameters of a predictive model based on statistical analysis of the spatial distribution.
2. to examine the anomaly responses and characteristics, if any, created by the presence of unfired clay brick walls lying on beds of the natural alluvial clays from which they were derived.
3. to compare and augment previous years' results of resistivity survey and long-range remote sensing (SPOT and aerial photography) with those of this season's magnetometry and magnetic susceptibility.

The principal geophysical instruments used were the MS2 susceptibility meter with an MS2D 10cm search loop — kindly donated for the season to the IMP by Bartington Instruments (note 1) — and the Geoscan Research (note 2) FM18 fluxgate gradiometer belonging to the Institute of Archaeology, University College, London. The software used to provide statistical analysis and graphical presentation of the results was AgriMensor (note 3).

4 Approach and methodologies

An area of some ten hectares — and having the continuing excavations at Trench 4 (note 4) as its approximate centre — was believed to have been specifically utilised for predominantly industrial purposes during the Early Islamic period. It was hoped that use of magnetic detection instruments might aid in confirming this hypothesis, at the same time identifying the area's physical boundaries and establishing any pattern in the groupings and layout of the kilns, furnaces, slag heaps and associated workshops.

The area was firstly scanned by field-walking accompanied by the site metallurgist; this was then repeated using both field instruments (the FM18 in analogue display mode) in areas selected by the metallurgist as being of special interest.

Where possible, the areas immediately surrounding Trench 4 were examined in detail since excavations in this trench had revealed considerable industrial activity alongside domestic accommodation. Seven 20m x 20m grids to the immediate north and to the immediate west of the trench (the eastern side contained the spoil heap and could not be easily accessed) were subjected to a full magnetometer survey at 0.5m station and traverse intervals — a total of 11,200 readings. Fig. 1 indicates the general layout of this area, together with the resulting patterns obtained; these are explored in further detail below. The large blank area to the east of the diagram represents the position of the westerly edge of Trench 4; the small blank area to the west of the diagram represents readings which have been discarded as unreliable due to adverse climatic conditions affecting the magnetometer's electronics.

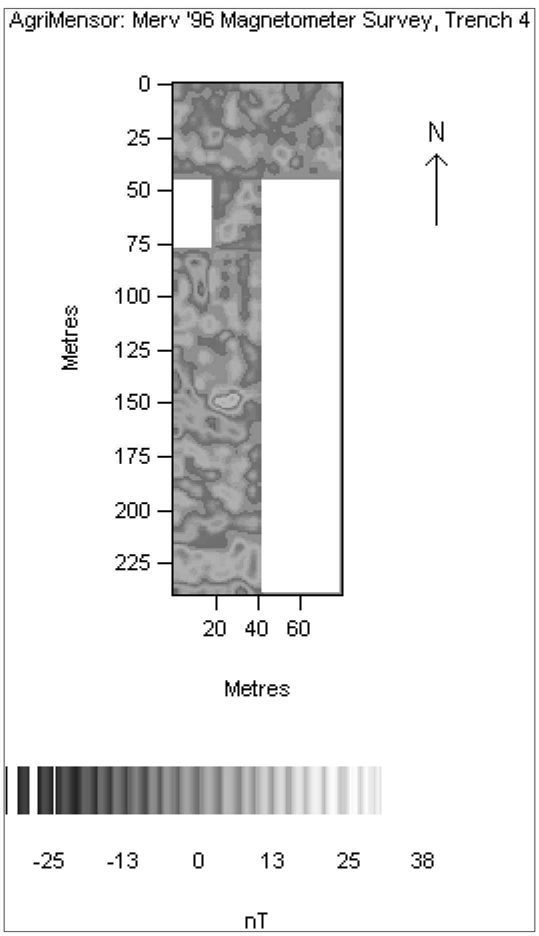

Figure 1. Results of magnetometer survey surrounding Trench 4.

To the immediate south of the trench a systematic magnetic susceptibility survey (30m x 30m at 0.5m station and traverse intervals) was taken — a total of 3,600 readings.

Sampling using magnetic susceptibility has become a recognised survey procedure for the appraisal of large areas and is well documented in sources such as David (1995) and Clark (1996). However, the relatively undisturbed conditions in this area of the site, together with the largely unbroken and homogeneous nature of much of the terrain and topography surrounding it, permitted rapid sampling at significantly closer station intervals than would normally be available to users of this prospecting technique. These conditions, then, provided a near-unique opportunity to pioneer the use in geophysics of the method known as Stratified Systematic Unaligned Sampling (SSUS).

Amongst its various uses, SSUS may be utilised to ascertain whether one particular part of a site is statistically different from another part *vis-à-vis* a particular site characteristic. The method owes its origins to the spatial analysis of settlement patterns by Haggett *et al.* (1977); the technique together with its statistical benefits are more fully described in Shennan (1988).

Stratified Systematic Unaligned Samples were taken using the MS2D in three different 30 m x 30 m sub-areas identified by the metallurgist as possibly worthy of further investigation.

5 Field application of the SSUS method

Conventional systematic sampling using magnetic susceptibility is normally based on a simple grid system with fixed station intervals as shown in Fig. 2. In this system, the location of the sampling position is at each cell's geometric centre (Clark 1996).

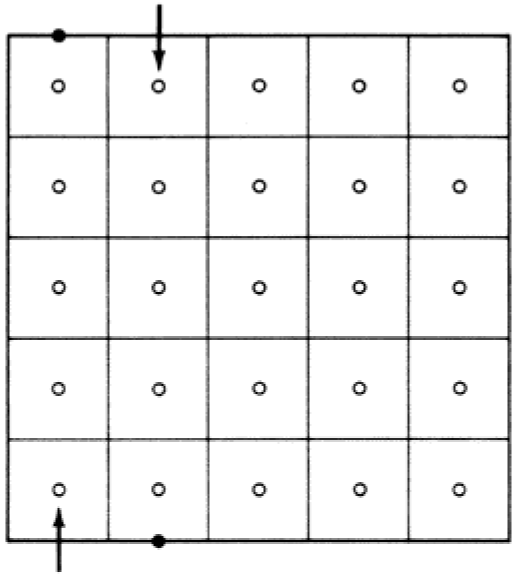

Figure 2. Standard sampling grid (after Clark, 1996).

Stratified Systematic Unaligned Sampling is a technique which combines the advantages of stratified random sampling and systematic sampling. Using SSUS, the sampling position from cell to cell varies in such a way that whilst spatial regularity is still systematically maintained, each cell also acts as the stratum or subdivision from which an independent random sample is taken. The method promotes an even, non-periodic sampling technique across a given population and can lead to more precise results in situations where variance in the sought characteristic is inter-strata rather than intra-strata. The following procedure is used to determine the sampling position within each cell:

1. The location of the first cell's sampling position is determined by the separate random selection of its *x* and *y* co-ordinates (Fig. 3a).
2. For the remainder of the first row, use the same *x* co-ordinate offset from each cell's respective origin, then define each cell's *y* co-ordinate offset from the origin by new random selection (Fig. 3b).
3. For the remainder of the first column, use the same *y* co-ordinate, offset from each cell's respective origin, then define each cell's *x* co-ordinate offset from the origin by new random selection (Fig. 3c).
4. To establish the location of each remaining cell's sampling position, use the *x* co-ordinate of the row in which it appears and the *y* co-ordinate of the column in which it appears (Fig. 3d).

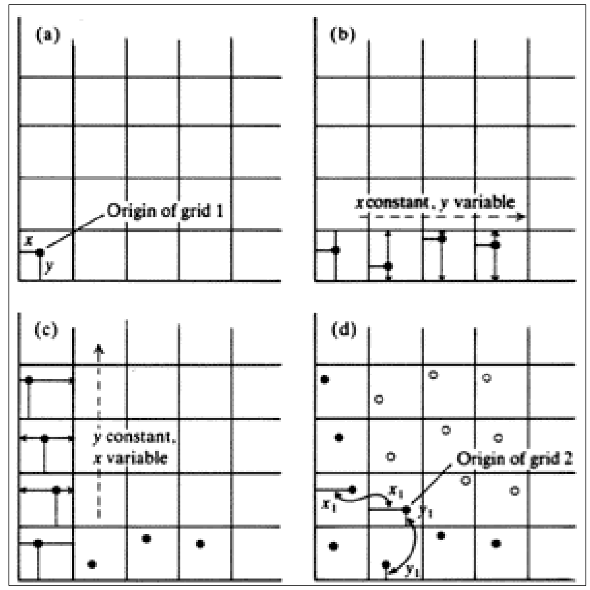

Figure 3. Building an SSUS susceptibility grid (after Shennan 1988 and Haggett *et al*. 1977).

The location of every sampling position is now stratified by cell, whilst avoiding both auto-correlation and periodic repetition yet still displaying a regular distribution (Fig. 4).

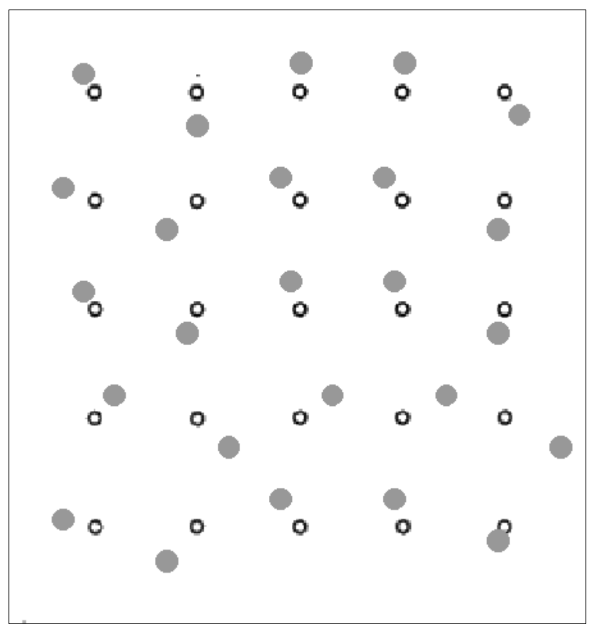

Figure 4. Comparison of standard grid with a typical SSUS grid.

In the field, sampling was performed using grid cells of 1.5m x 1.5m, giving a total of 1,200 such samples across three putative areas of functionally differentiated occupation.

In the absence of an on-site PC, each set of the initial 39 pairs of random co-ordinates for each sub-area were conveniently generated in the field by the roll of two dice. The same exercise was then repeated using a different series of cell co-ordinates thus making a final total of 2,400 samples. The purpose of this second run was primarily to provide a check-in-balance of the results from the first, but was also valid as a separate set of samples in its own right since auto-correlation between sample intervals must *de facto* be non-existent (effective susceptibility sphere of 10 cm diameter in cell proximities ranging from 0.5m to 2.5m).

In addition to general prospecting and scanning, a total of 17,200 magnetic readings were systematically recorded.

6 Results

An inherent advantage of this season's magnetic methods over those of previous years' resistivity surveys is that those areas which in the 1993 season could not be measured due to compaction (Strange 1994, & Herrmann and Kurbansakhatov *et al.* 1994) were now able to be re-surveyed. Figs. 1 and 5 show quite clearly the 'sunken way' running in an approximately east-west direction together with the retaining walls of building frontage to both the north and south showing at the 22 and 37 half-metre intervals.

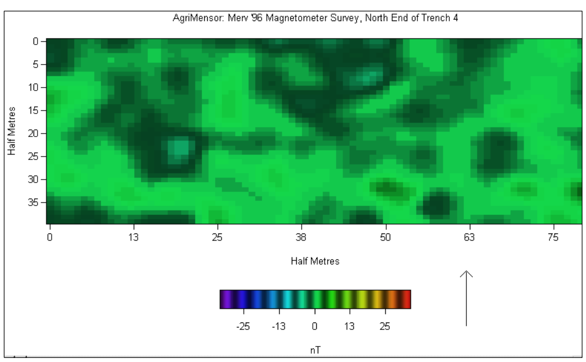

Figure 5. Detail of magnetometer survey to the immediate north and to the north west of Trench 4.

An extremely large, irregularly shaped refuse pit in excess of 2m diameter and of indeterminate depth was located and partially excavated (Trench 4_5, Fig. 6). The pit predominantly contained deposits of broken pottery ranging from large fragments of course ware vessels through to quite delicate pieces. Significant small finds included copper slag, bronze and iron metalwork, animal bone and glass vessels. As might be expected, such a pit was indistinguishable in the geophysics from kilns and furnaces. Negative linear anomalies within the same grid are attributed to mud brick walls.

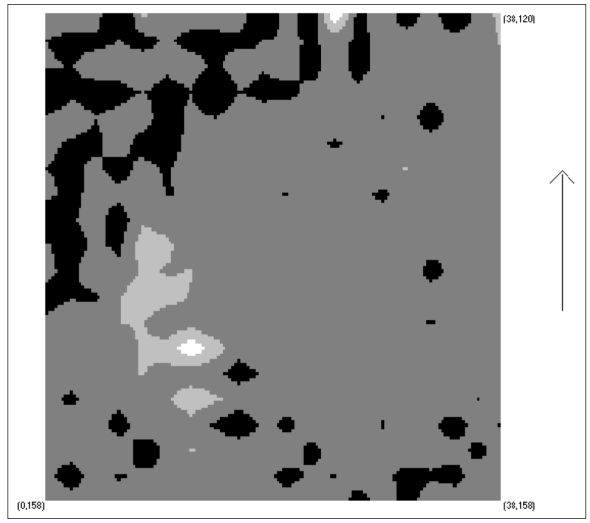

Figure 6. Smoothed data showing pit with adjacent buildings.

A number of furnaces for use in metal production were successfully located using both magnetic methods within and without the detailed survey areas, verification was made possible by subsequent trial excavations.

The previously formulated null hypothesis that the 'industrial area' contained more than a reasonably expected number of kilns/furnaces per hectare was rejected by the initial SSUS results (a = 0.05). As noted above, sampling was repeated, only to demonstrate the same result. Hence the concept of a specialised 'industrial area' at this location was not borne out by the geophysics results.

Under certain circumstances, some areas of unfired clay bricks show as negative anomalies in the results. The tendency for this to happen was not constant across the site. A number of reasons have been postulated for this, amongst them the following:

1. Differences in the magnetic profiles at various points within such a large site are inevitable due to differing alluvial and geological conditions; however, it is unusual for them to be as pronounced and as numerous as at Merv, even allowing for the fact that the archaeological park extends to more than ten square kilometres. At

least three completely different profiles were noted — there may well be more;
2. More than 24 hours of continuous torrential rainfall two-thirds of the way into the period of survey subsequently changed the capacity of these bricks to be detected. It is supposed that absorption of the water by both the bricks and the alluvial clays on which they lay (and from which they were originally made) affects the magnetic contrast, perhaps due to detrital effects (Clark *et al.*1988) or oscillating chemical reduction and oxidation (Le Borgne 1955 & Le Borgne 1960);
3. Some of the bricks are indigenous to the immediate area in which they are found — others are transported to the site from outside the cities' walls, the clays therefore exhibiting different magnetic characteristics (weak and strong negative anomalies respectively). This was markedly demonstrable by simply comparing susceptibility results from adjacent bricks (see Fig. 7).

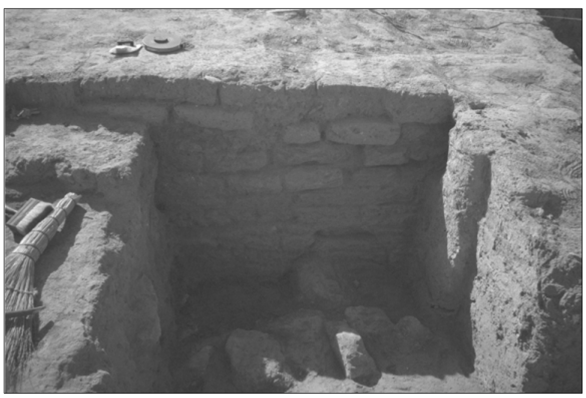

Figure 7. Unfired mud bricks *in situ* alongside others of different provenance.

The area of Grid 4 to the west of Trench 4 is shown in Fig. 8. Traces of such bricks are indicated by negative anomalies running approximately N-S and E-W. It would, however, be speculative to attempt any further delineation of the buildings without the benefit of archaeological excavation.

The area within Shariyar Ark was subjected to a short systematic magnetometer survey (20m x 20m grid with 0.5metre station and traverse intervals) in order to verify the existence of walls which had been identified in earlier aerial photography. More details are given elsewhere by Barratt, Bullas and Doyle (this volume).

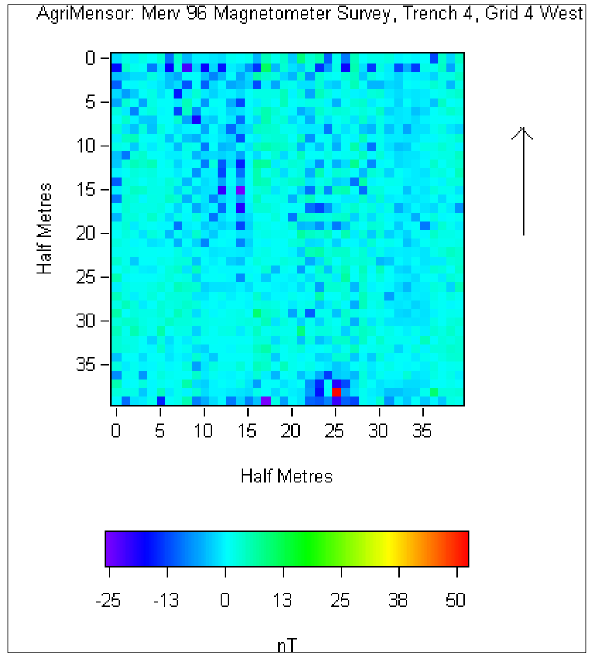

Figure 8. Traces of unfired clay bricks showing as negative anomalies.

7 Summary

It did not prove possible for the geophysics to confirm the existence of a specialised industrial area at the suggested location in Merv. Rather than being a failing of the method, the statistical conclusions point to the fact that the original hypothesis should be rejected.

Use of systematic gradiometer surveys in conjunction with susceptibility sampling has confirmed that it is indeed possible to detect unfired clay bricks lying on top of the clay from which they were made, but only under certain climatic and geological conditions. It may prove prudent for further future research to be carried out in confirming the extent and nature of these variations.

The results of this year's survey fitted well with the theories and conclusions of previous surveys and with the existing remote sensing data as far as the foundations of substantial walls and buildings were concerned.

Acknowledgements

Many thanks are due to Bartington Instruments, firstly for the loan of the MS2 magnetic susceptibility meter and secondly, for not having complained at the desert-weary state in which it was returned to them!

Prior to the start of the Project, a large number of archaeological geophysicists were consulted — in the UK, Egypt, Eire, Jordan and the United States — regarding the likelihood of obtaining meaningful results from unfired mud bricks laying on the alluvial clays from which they were made. Upon completion of the project, many of these colleagues were asked to comment on the results obtained. My sincere thanks go to all of these, but particularly to Dr. Kate Clark of the University of Southampton, posthumously to Dr. Tony Clark who made many helpful suggestions and donated some of the measuring equipment and to Dr. Chris Gaffney of Geophysical Surveys of Bradford.

Notes

1 Bartington Instruments Ltd., 10 Thorney Leys Business Park, Witney, Oxford OX8 7GE, England

2 Geoscan Research, Heather Brae, Chrisharben Park, Clayton, Bradford, West Yorkshire BD14 6AE, England

3 AgriMensor is distributed by Strategic Decisions Ltd., Park House, 158–160, Arthur Rd., Wimbledon Park, London SW19 8AQ, England

4 As an aid to consistency, references used in this paper to trenches and other areas of excavation are synonymous with those used in Herrmann, Kurbansakhatov, *et al*. 1994 and by Barratt, Bullas & Doyle elsewhere in this volume.

Bibliography

David, A, 1995 *Geophysical survey in archaeological field evaluation*, Research & professional services guidelines No. 1.

Clark, A J, Tarling D H, and Noël, M, 1988 Developments in archaeomagnetic dating in Britain, *Journal of Archaeological Science* ,15, 645–667.

Clark, A J, 1996 *Seeing beneath the soil — prospecting methods in archaeology*, London.

Haggett, P, Cliff A D, and Frey, A, 1977 *Locational analysis in human geography*, 2nd. Edn., London.

Herrmann, G, Kurbansakhatov, K, et al., 1994 The International Merv Project — Preliminary Report on the Third Season, *Iran* XXXIII, 40–41, figs. 3–5, London.

Le Borgne, E, 1955 Susceptibilité magnétique anormale du sol superficiel, *Annales de Géophysique* 11, 399–419.

Le Borgne, 1960 Influence du feu sur les propriétés magnétiques du sol et du granite, *Annales de Géophysique 16*, 159–195.

Shennan, S J, 1988 *Quantifying Archaeology,* 323–328.

Strange, P, 1994 Results of the 1993 geophysical survey at Merv. Pers. comm.

Contact details
Stephen Bullas
Strategic Decisions Ltd
Park House
158-160 Arthur Rd, Wimbledon Park
London SW19 8AQ
UK
e-mail: AgriMensor@compuserve.com