WROXETER, THE *CORNOVII* AND THE URBAN PROCESS

FINAL REPORT ON THE WROXETER HINTERLAND PROJECT 1994-1997

VOLUME 2: CHARACTERIZING THE CITY

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with

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ACKNOWLEDGEMENTS

Little did we suspect when we first published a paper on the geophysical survey being carried out at Wroxeter (White 1996) that the results of this ambitious project would provide information for two volumes on the results of the survey and form a key component in a third volume, funded through Leverhulme and English Heritage, investigating the impact of urbanisation at Wroxeter on Cornovian society. Not surprisingly, the journey that eventually led to an *insula* by *insula* analysis of the town took some considerable time to complete, although a basic draft had been compiled in 2000 to meet the deadlines for English Heritage funding. It was always intended to work up this version to a full text but a preliminary methodological volume, designed to get the base data out to a wider public was prioritised and published first (Gaffney and Gaffney 2000). Following this it was decided to finalize and complete the results of the larger Leverhulme research project within which the survey took place and this major undertaking took a total of seven years to complete (Gaffney and White 2007). After that, attention could turn to the Atlas. The gap between publications was significant but this also had a number of benefits. It was clear, for instance, that the original survey had been inspirational to many researchers and that it formed a significant milestone in the invigorated development of remote sensing survey throughout Europe. The benefits of research at such a large scale were appreciated by many archaeologists and the surveys which followed Wroxeter, in Italy for instance, and the large scale projects which have since pioneered novel and rapid sensor arrays owe something at least to the work carried out at Wroxeter during the 1990s (http://archpro.lbg.ac.at/). The process of writing, even with the significant publications which had proceeded the current text, was arduous and fell substantially on the principal author (RHW) who had, in the interim, also been involved in researching and writing critical analyses of the site (White 2010; White, Marriott and Reid 2012). This has meant sacrificing many days and weekends and he would like to acknowledge the tremendous support of his family in this. Critical to completion was the opportunity to work in complete isolation at Upton Cressett gatehouse for two weeks in January 2012, due to the kind offices of William Cash. This opportunity was only made possible by the support of the Institute of Archaeology and Antiquity and the College of Arts and Law who granted sabbatical leave for the semester in 2012. The resulting document was commented on by Simon Esmonde Cleary to its considerable benefit and conversations with Gareth Sears and Ray Laurence were also extremely helpful to us, as was the continuing support to the project offered by Prof. Mike Fulford.

In the first volume of the report, we gratefully acknowledged the help and support of the hundreds of volunteers on the project along with many academics who had advised and supported the project. We wish to thank them all heartily again but would note in particular those colleagues who, since 1996, have assisted in the geophysical work in particular. Of key importance was the commitment shown by the teams at GSB Prospection, led by Chris Gaffney and John Gator, and English Heritage Geophysics Unit, led by Andrew David and including Neil and Paul Linford and Andy Payne. Between them these recorded the entire site and processed the data with the English Heritage team pulling the final complete plot together. Other research teams were encouraged to bring their often experimental devices to the site including those from CNRS, led by Albert Hesse and including Michel Dabas and Jeanne Tabbagh, and the Nara Research Institute team led by Yosushi Nishimura and Dean Goodman. Joerg Fassbinder, Paul Cheetham, ArchaeoPhysica (Martin and Anne Roseveare), Roger Walker and Ruth Murdie of Keele University participated through English Heritage sponsored public events or by invitation from English Heritage or the authors. Mark Corney generously donated his time to carry out a survey of the riverbank area of the site. Without their unstinting effort, this volume would not have been possible, but the critical input of English Heritage in facilitating this activity is acknowledged. Critical too was the co-operation of English Heritage Inspectors, notably Gill Chitty, Tony Fleming, Heather Sebire and Bill Klemperer, in providing Scheduled Monument Consent, often at short notice, for the works to continue. Similarly, the support of the National Trust regional archaeologist Jeremy Milne is gratefully acknowledged.

The aerial photographs that grace the report and which have added immeasurably to our understanding of Wroxeter were generously donated by Dr Arnold Baker along with all his plots. These will in due course be deposited in an appropriate archive. We are also extremely grateful for the generous donation of the colour view of the town taken by Alistair Reid which has visualized the importance of the landform of the monument.

The work reported on here was in the first instance generously funded by the Leverhulme Trust whose support we would like to acknowledge here. The post-excavation project was taken on by English Heritage staff and we are grateful in particular for the advice and support provided especially by Barney Sloane,

Sarah Reilly, Magnus Alexander and Kath Buxton who were instrumental in keeping us on track and agreeing to fund the project. We are sure that they are as relieved as we are to finally see this into print.

We would also like to acknowledge and thank all our colleagues in Birmingham University Field Archaeology Unit (BUFAU) and its more recent incarnation, Birmingham Archaeology (BA). They were vital in providing the professional and technical support essential to the smooth running of the project. Singling out individuals is invidious but in particular we wish to thank the geophysical team including Sally Exon, Helen Goodchild, Steve Wilkes, Meg Watters and Eamonn Baldwin, the drawing office team comprising Mark Breedon and Nigel Dodds and the Department's photographer Graham Norrie. Without them, and all of our other colleagues in BUFAU / BA we would not have been able to carry out this project and so it is with great sadness that we write this during the time of the demise of BA. The University of Birmingham has had a proud involvement in Wroxeter Roman City since 1952 through luminaries such as Graham Webster, Philip Barker and Philip Rahtz. Countless Birmingham students and others from many Universities have worked and been trained on the site, including the principal author whose first involvement with the site was on Graham Webster's University of Birmingham training excavation in 1976.

In the current economic and higher education climate it is difficult now to imagine how such work can continue through a higher education institution alone. As is clear from the final paragraphs in the volume, we do not envisage this being the end of the work on Wroxeter Roman City, but it is difficult not to come to the conclusion that this vital work needs to find innovative ways of funding if work is to continue and undertake further investigation on the site. Ideally, the challenge will be taken up by the site's owners: English Heritage, who have so generously funded the work on this, and the other five volumes that have published the results of the post-1945 investigation of the site.

CHAPTER 1: BACKGROUND

1.1 THE RESEARCH CONTEXT OF THE WROXETER HINTERLAND PROJECT

The work on Wroxeter Roman City reported on here arose as a direct consequence of the Wroxeter Hinterland Project. The aim of the project, as outlined in the First report, was to determine the economic relationship between the town and its hinterland through extensive surface survey and targeted excavation within a defined hinterland (Gaffney and White 1997, 64). However, one of the key research aims was also to determine whether the hinterland was capable of producing enough food to support the town's population. To answer this question it became critical to know, within the life of the project, what the likely population of Wroxeter was at its maximum occupancy. Earlier researchers had suggested that Wroxeter was a relative failure and that the northern part of the town was devoid of buildings, with the majority of the town's buildings confined to the area south of the Bell Brook. The defences thus enclosed enough land to feed the population living in its scattered buildings within its defences and presumably in dread of hostile native peoples beyond (Richmond 1963, 259-61). This model was unprecedented, as Richmond himself acknowledged, but needed testing. The response was to commission the geophysical survey reported on here.

In the mid 1990s, geophysics was moving into a new phase related not so much to technological developments but to vastly increased processing power that meant that large amounts of data could be gathered and processed rapidly. As a result of the combined efforts of the Ancient Monuments Laboratory and Geophysical Surveys of Bradford, the entire area of the walled town was surveyed using magnetometry. Other geophysical technologies were also used, and are reported on here in the remainder of this chapter, while the technical reports associated with these various surveys have been reported on elsewhere (Gaffney and Gaffney 2000).

The aim of this study is to realise the archaeological potential of these surveys by combining their data with existing data from excavations and from other remote sensing surveys, notably aerial photography. Partly the aim has been to offer some means of ground truthing the results of the geophysical survey: how can we be absolutely confident that the responses detected in the survey represent buildings? Normally this would be achieved through excavation but this was not possible given that the monument is protected and in any case it would have been impractical to sample across the whole site within the time-frame available to us. Plotting the results against the detailed maps resulting from aerial photographic surveys over the town demonstrates clearly the excellent correlation between the two, as is demonstrated in Table 1.1. From this it can be seen that in the aerial photographic survey 93 buildings and eight public buildings are visible in *insulae* I-XVI whereas for the same area the magnetometer survey can see 97 and seven respectively. However, for the remaining area of the town, the disparity between the two is marked with the magnetometer able to see 118 in contrast to the 26 visible in aerial photographs (both can only see one public building).

INSULA NO.	NO. OF BUILDINGS (AP)		NO. OF BUILDINGS (SURVEY)	
	Private	Public	Private	Public
I	1	1	2	1
II	15	-	16	-
III	3	1	4	1
IV	1	1	1	1
V	1	1	1	1
VI	6	-	5	-
VII	3	-	3	-
VIII	16	2	13	1
IX	6	-	6	-
X	5	-	6	-
XI	3	-	4	-
XII	6	1	14	1
XIII	1	1	2	1
XIV	-	-	1	-
XV / XXIX	12	-	10	-
XVI	14	-	9	-
Sub total	93	8	97	7
XVII	-	-	-	-
XVIII	-	-	3	-
XIX	1	-	2	-
XX	1	-	6	-
XXI	-	-	5	-
XXII / XXIII	1	-	3	-
XXIV	2	-	1	-
XXV	-	-	1	-
XXVI	4	-	5	-
XXVII	-	-	5	-
XXVIII	-	-	1	-
XXX	5	-	5	-
XXXI	-	-	3	-
XXXII	4	-	6	-
XXXIII	2	-	7	-
XXXIV	-	-	5	-
XXXV	-	-	6	-
XXXVI	1	-	6	-
XXXVII	2	1	4	1
XXXVIII	-	-	1	-
XXXIX	1	-	3	-
XL	1	-	3	-
XLI	-	-	4	-
XLII	+	-	2	-
XLIII	-	-	6	-
XLIV	-	-	5	-
XLV	-	-	8	-
XLVI	-	-	5	-
XLVII	-	-	4	-
XLVIII	-	-	3	-
Sub total	26	1	118	1
Total	119	9	215	8

Table 1.1: Comparison of number of buildings visible within Wroxeter using aerial photographic sources and the magnetometer data (after White and Gaffney 2003, revised); cf. Table 4.1 for combined figures.

This aim of this volume is to present a detailed interpretation of the town using the combined evidence of the magnetometer data and aerial photography. The results are presented *insula* by *insula* in Chapter 3, the Wroxeter Atlas. Chapter 2 supplements the geophysical survey by presenting the results of small-scale excavation and evaluation between 1999 and 2005. These excavations are seemingly trivial — a series of 20 or so small-scale trenches 2m x 1.5m in size and up to 2m deep, yet because they traverse the entire town from north to south, they provide a unique sample across the monument, often in areas that have not been investigated before scientifically. A second excavation is also reported here. It was carried out in 2005 under the aegis of the Institute of Archaeology and Antiquity, University of Birmingham and had two objectives: to train its postgraduate students and investigate two anomalies: a putative church detected in the geophysical survey and a possible robbing pit. Although the results of the geophysical surveys have not been tested by excavation, precluding detailed chronological analysis, there is enough visible of the street plan and wider landscape to enable broad chronological development to be discerned, underpinned wherever possible by other archaeological data. This analysis is presented in Chapter 4.

The Atlas offers the most complete survey of a Romano-British town currently available. Although far more is known about Silchester following the extensive excavations carried out in the Victorian period followed by the sustained research over the past 40 years by Mike Fulford (Fulford 1984; Fulford 1989; Fulford and Timby 2000; Fulford, Timby and Eckhadt 2006; Fulford and Clarke 2011). As yet there is no complete combined geophysical, aerial and excavated plan of Silchester although one is to be published shortly (Creighton, in preparation). The closest parallel to the approach adopted here at Wroxeter has been the aerial survey of *Venta Icenorum* (Caistor-by-Norwich) and the more recent geophysical survey, albeit on a much smaller scale. In both cases the results are not as clear cut as they are with Wroxeter, perhaps as a result of different underlying geological factors or even different constructional techniques for the buildings (Wilson 2003; Bowden and Bescoby 2008).

Looking abroad, similar surveys have begun at Aquilea, Italy, this too linked to a GIS software to facilitiate interpretation (Buora and Roberto 2010), at *Amiternum* where integrated geophysics and field survey were used between 2006-10 to map the site (Christie 2012, 26-7), at Italica in Spain (Creighton *et al*. 1999), at Nijmegen in Holland (Willems and van Enckevort 2009) at Xanten, Germany (Müller, Schalles and Zieling 2009). However, the closest parallel to our work is the long-term research programme to map the city and landscape around *Carnuntum* in Austria through GIS, rectified aerial photography and geophysics (Doneus and Scharrer 1999).

The site at Xanten offers an interesting parallel for Wroxeter. Xanten, like Wroxeter, was taken into government control in the mid 1970s (in this case it was the regional authority, the Landes Nordrhein-Westfalen). Work immediately proceeded on clearing an unfortunate modern industrial development that had been permitted on the site in the 1950s and 60s and then survey, excavation and reconstruction got underway over the whole town. As is now widely known, the site, which is virtually identical to Wroxeter in area, has now been completely cleared and a number of public buildings have been reconstructed on the excavated remains of the Roman period. The site is a major tourist attraction — *Colonia Ulpia Traiana* (CUT) — offering a fascinating contrast in approach to the presentation of Roman remains to the examples seen in Britain. Yet, despite the enormous sums expended on the site, the plan presented in the frontispiece of the latest Xanten volume (Müller, Schalles and Zieling 2009) is by no means comprehensive: there are still whole *insulae* on which nothing is plotted away from the core of the town. On the reconstruction of the town on the cover of the book, however, building density is shown as uniform across the site but this is by no means certain on the evidence presented. It is doubtful that Wroxeter will ever be fully excavated in the way that Xanten has been, although a building has now been reconstructed at Wroxeter too, albeit a fanciful one that does not relate to the underlying archaeology, unlike at Xanten. For the moment, the geophysical surveys and aerial photographs of the site will remain our surest way to understanding this complex monument.

1.2 REVIEW OF PREVIOUS REMOTE SENSING AT WROXETER

Early accounts of the site at Wroxeter are lacking with the first recorded description being that of Camden who describes the Old Work, apparently much as it appears today, and the circuit of the defences:

> '*Here is nothing to be seen of it, but a very few reliques of broken walls, call'd by the people* The old works of Wroxceter, *which were built of hewn stone, and laid in seven rows, arch'd within, after the fashion of the Britains. That where these are was formerly a castle, is probable from the unevenness of the ground, heaps of earth, and here and there the rubbish of walls*' (Gibson's Camden 1695, 544).

This account is corroborated by all other early descriptions of the site which focus only on the visible elements of the site: the central ruined wall and the earthworks of the defences. Local people knew better: the earliest account of a building from Wroxeter is the description by Dr Lyster of the hypocaust found in 1701.

> '*About 40 perches distant North from a ruinous wall … in a piece of arable land, in the tenure of Mr Bennet, he observed, that although these fields had formerly been fertilized and made very rich by the flames and destruction of the city, yet a small square parcel thereof to be fruitless, and not to be improved by the best manure. He then guessing the cause of sterility to be underneath, sent his men to dig and search into it;*

Figure 1.1: Cropmark of an apsidal room in a building on *Insula* II, visible in the 1994 drought. (Photo R. White)

Figure 1.2: Plan of Uriconium by Percy Taylor, 1931. Note the street grid which is based on Bushe-Fox's plot (Shropshire Archives).

Figure 1.3 Arnold Baker (rear seat) in a DH82a Tiger Moth, complete with photographer and F24 camera. (Photo courtesy A. Baker)

> *but the soil being then unsown, caus'd them to mistake, and search in the wrong place; where they happen'd upon bottoms of old walls, buried in their own rubbish, (being such as are often found in those fields;) and the inhabitants digging one of them up, for the benefit of building stone, were thereby guided to the Western corner of said unprofitable spot of land: where they found (near the foundation) a little door-place which, when cleaned gave entrance into the vacancy of a square room, walled about, and floored, under and over, with some ashes and earth therem* (sic).' (Lyster 1706, 2226).

Writing nearly a century later, Thomas Telford confirmed this practice based on his own experience: '*the stone foundations at no great depth under the surface of the ground, are manifest in long-continued drought; so that when the occupiers of the land need any stone for building, they mark the scorched parts, and after the harvest, dig out what suits their purpose*.' (Rickman 1838, 23). People living on the site were thus very aware of the effect of parching in the fields and this is a phenomenon that still appears today, even in the less responsive pastureland that Wroxeter has now become since its purchase by the State in the mid 1970s (Figure1.1).

These effects were mapped for the first time by Bushe-Fox who, while digging in *insula* VIII in 1912-14, noted that in the field on the other side of the road (i.e. the field south of the baths) parch-marks of the underlying streets began to appear in drought conditions (Bushe-Fox 1913, 3). In the author's experience, these marks are the first to appear and can be observed on a regular basis, even appearing on GoogleEarth™. These marks were plotted by Bushe-Fox and then appeared on later plans of the site in his report and those of others.

The major period of discovery of the site came after 1945 when the potential of the site for aerial reconnaissance was first realised (Barber 2011, 216-220). There had been recorded flights above Wroxeter before that time, however. In 1928, Sir Charles Marston had commissioned Aerofilms to photograph the ruins of the baths, the results being published in the Transactions of the Shropshire Archaeological Society (Morris 1929; the photos themselves are now in the NMR: AFL03 25 28866-8). While of tremendous value for recording the state of the ruins and visitor attraction at that date they tell us little of the rest of the town. Fortunately, at an almost exactly contemporary date, the remains of the town were formally surveyed, as was the baths site, at a large scale by Percy Taylor (Figure 1.2).

This plan has never been published before but shows the form of the defensive earthworks before modern ploughing modified them and provides the only record of the spoil heaps on the baths site before their clearance. Other photographs, taken in 1938 by Group Captain Livock an amateur archaeologist who at that time was in correspondence with Lal Chitty, doyen of Shropshire's prehistory, once again focused on the ruins (NMR GEL 9370 frame 369).

Post-1945, however, the opportunities to carry out aerial photography survey were significantly easier. First, the aircraft and equipment (mostly the F24 camera) were readily and (relatively) cheaply available (Baker 1992, 15-40; Figure 1.3). Second, and more important there were committed individuals with the necessary skills to carry out the task: there have never been more trained aircrew available in Britain than in 1945. Not just pilots but also Navigators and Observers. Archaeologists had been employed too in the Intelligence Service during the war, Glyn Daniel for instance, largely because of their interpretative skills in the analysis of aerial photographs whether oblique or vertical. To such men the opportunity to keep up their flying skills while also pursuing their archaeological interests was too good to miss leading to a golden generation of aerial photography in Britain.

At Wroxeter the principal photography was undertaken by Dr Arnold Baker, who began overflying the site in the mid 1950s (Baker 1992). Although ex-RAF, Arnold Baker had worked during the war for the Defence Research Establishment developing airborne Radar rather than serving as aircrew. Fortunately, he realised the supreme importance of photographing the site on repeated occasions over a number of years, his final flights occurring in the late 1970s. His thesis, on the aerial archaeology of the Upper Severn Valley, was produced in 1992. By that time, Chris Musson of Clwyd Powys Archaeological Trust had taken over the task of methodical flying over the monument, commissioned by Shropshire County Council or by English Heritage. Occasional flights were also made by Jim Pickering and also by J.K .St Joseph and D.R. Wilson of the Cambridge University Committee for Aerial Photography (CUCAP). The latter’s flights in the drought years of 1975 and 1976 have proved to be particularly important (Watson and Musson 1993, 46-48; Wilson 1984). Skyscan Photography also took photographs using large format cameras slung from a tethered balloon on some parch-marks north of the baths in the drought year of 1994. Occasional flights by Andy Wigley of Shropshire Council are still undertaken, funded by English Heritage.

Publication and interpretation of the results from these flights was relatively slow. J.K. St Joseph’s publication of his 1946 photograph of a house on *insula* IX led to the small-scale training excavation in 1953-4 by Kenyon and Webster which permitted the first test of the relationship between the aerial photographic evidence and the structures beneath the surface (Kenyon 1980, plate 1).

The first discussion of the results of the overall photography was that by Graham Webster and Brian Stanley (1964) which divided the town into a number of areas according to their responsiveness to aerial photography but did not try to attempt to identify zones of activity.

Webster revisited his ideas on this subject a number of times but his paper offered as a contribution to Derrick Riley’s *Festscrift* was his latest and most focused reinterpretation of the results (Webster 1989). Baker published a number of papers discussing particular aspects of the interpretation of his aerial photographs (for example 1968 and 1970) followed by his thesis in 1992. The most widely known paper on the interpretation of the results, however, was that published by David Wilson of the Cambridge University Committee for Aerial Photography (CUCAP) interpreting the results of the drought- year photographs of the mid 1970s (Wilson 1984). The deliberate exclusion from this plan of the cropmarks of trackways and other features in the northern part of the town led Philip Barker to respond by publishing a detailed plan of this area using aerial photography, discussing features seen inside the town in relation to the defences (Barker 1985). An integrated plan, drawn from the work of Baker, Barker and Wilson was produced by the late 1980s and was used by Webster (1989, 1993) and, in an altered fashion, by Wacher (1995). The final discussion worth noting is that given by the current authors of this volume in 2003 which gave the first overview of the integrated results of the aerial photographic survey and the geophysics results (White and Gaffney 2003).

1.3 THE NEED FOR PROSPECTING WITHIN THE ROMAN TOWN OF WROXETER

The Wroxeter Hinterland Project was the vehicle for one of the one of the most ambitious programmes of archaeo-geophysical survey carried out at the end of the last century and the primary data, published as a special issue of *Archaeological Prospection*, provided what was then an unparalleled plan of the Roman town (Gaffney and Gaffney 2000). The rationale for such a survey was clear; the Wroxeter Hinterland Project sought to carry out integrated archaeological research on the linked questions of urban–rural relationships and Romanization and was centered on an investigation of the impact on the development of the *civitas Cornoviorum*. From the outset we believed that the Roman city at Wroxeter was appropriate for such study. Covering an area of nearly 78 ha., Wroxeter was the fourth largest urban centre in Roman Britain and benefited from the relative absence of medieval and modern development in the area (White and Barker 1998). However, the town had, unsurprisingly, attracted the regular attentions of antiquarians and archaeologists. This culminated in the publication of what appeared to be a comprehensive plan of the town derived primarily from aerial photography by Wilson in 1984. However, in the context of the proposed research in 1994, the plan raised a number of problems that were not readily solvable. There was an apparent conflict between the size of the area enclosed by the town’s walls, the relative wealth of excavated information that was being provided by its principal buildings, and the apparent lack of structures over considerable parts of the enclosed area. As much as 40% of that urban zone within the walled area was effectively uncharacterized and the interpretation of the wider study area rapidly became dependent upon further and more detailed information on the structure of the town itself.

The value of the Wroxeter geophysical survey as published can hardly be questioned and did, indeed, provide the primary data for a large modeling exercise to assess the resource requirements to maintain the urban population, which was derived from study of the geophysical data (Gaffney and White 2007, 258-69). However, the data provided in the original *Archaeological Prospection* publication in 2000 represented only one phase of survey on the site, albeit a highly significant one. It did not attempt to publish in detail the totality of geophysical survey carried at Wroxeter and the majority of the work described below derives from work at the site contained within the, considerable, 'grey' literature.

There are many reasons why such surveys remain unpublished; some are small-scale and often dealing with emerging technology or methods, others are the product of teaching or outreach projects. Some of the surveys were simply demonstrations of techniques to interested parties. Examples of such a situation include the two open days at Wroxeter in 1997 that were jointly hosted by English Heritage and Birmingham Archaeology as part of Science, Engineering and Technology week (SET97). As a consequence, the data were never intended for rigorous peer-review and are held only by the data collectors themselves.

However, as will be demonstrated, the value of each individual piece of work is enhanced by the context of the mass of data collected at Wroxeter. Whilst it is hoped that the most significant geophysical 'events' have been traced for this summary, the nature of grey literature is that some small-scale data collections may remain unrecorded. This is true even though fieldwork at Wroxeter is controlled via guardianship status which requires an appropriate licence prior to any work.

The solid geology at the site is dominated by the red sandstone sequences of the Triassic series, with nearby Palaeozoic volcanic outcrops and pre-Cambrian 'Longmyndian' rocks associated with the Wrekin and the highlands to the south respectively (Earp and Hains 1971). Drift geology is largely composed of extensive glacial drift deposits of gravel, sand and boulder clay, although alluvium occurs around the river courses.

A cursory glance at David *et al.* (2008) Table 4 'Geology and the response to magnetometer survey' on page 15 would suggest little optimism for magnetometer survey at Wroxeter. This was an understood cautionary observation prior to the project. In fact, as will be described later, poor results have often been reported in the vicinity of the town, but the soils within any town, Roman or modern, are significantly altered due to anthropogenic factors. Neither the solid nor drift geology would indicate the true potential of magnetometer survey at this site.

1.4 A HISTORY OF GEOPHYSICAL SURVEY AT WROXETER

First we need to consider what exactly we mean by geophysical survey for archaeological purposes. At a crude level, many end users of geophysical data or images regard earth resistance and magnetometry techniques as 'geophysics'. For those who collect data, i.e. geophysicists, these are also catch-all definitions that broadly encapsulate the endeavour. For example, some simply consider all non-invasive techniques that assess the earth's physical properties, with the proviso that the data is collected at, or near to, the surface of the earth, to be geophysical. Consequently, while aerial or satellite information is not regarded within the remit of most geophysical surveyors, the digital nature and multi-methods approaches that are increasingly common means that the boundaries of investigations that involve geophysical techniques are increasingly blurred, especially as common aspects of visualization increasingly bring the various strands of 'remote sensing' together. However, the technical definition of geophysical survey can be terse and remote from the desired archaeological outputs. For example the current draft guidance from the UK based Institute for Archaeologists states:

> '*Archaeological geophysical survey uses non-intrusive and nondestructive techniques to determine the presence or absence of anomalies likely to be caused by archaeological features, structures or deposits, as far as reasonably possible, within a specified area or site on land, in the inter-tidal zone or underwater. Geophysical survey determines the presence of anomalies of archaeological potential through measurement of one or more physical properties of the subsurface*.'
>
> http://www.archaeologists.net/sites/default/files/node-files/geophysicsSG.pdf p. 2.

However this does not relate to either the archaeological interpretation of data or indeed the time depth that is apparent within such data (Gaffney and Gaffney 2011). Nonetheless, within the Wroxeter survey that was conducted in the late 1990s there was evident technical aspiration that the focus really was clearly toward the archaeological outcome. An additional aspect of the geophysicist's work is the scale of data collection and, hence, interpretation. Traditionally the scale of geophysical data collection was limited to the identification of individual features or small sites, but recent changes in technology have made the elucidation of archaeological landscapes within the remit of geophysical prospecting (Powlesland 2009).

A review of the literature demonstrated that the environs of Wroxeter produced some of the very earliest geophysical surveys for archaeological purposes. In the late 1950s and early 1960s Dr A.W.J Houghton (1959; 1964) reported a magnetometer survey over a Roman tilery at Ismore Coppice (some 200m north west of the town) and a resistance survey over a Roman pottery 'factory' a little further out and on the opposite bank of the Severn from Wroxeter. The former was undertaken by Martin Aitken, the designer of the first magnetometer for archaeological purposes (Houghton 1960) and was of great value in the subsequent excavation (Houghton 1961). This success presumably influenced the purchase of a proton gradiometer by the CBA West Midlands group in 1962 (anon 1963). However, there is no recorded geophysical survey from this period within the town itself. Despite this, the first survey using modern detection devices of a 'complete' Roman town was undertaken at Wroxeter towards the end of the 1990s and its publication remains a benchmark for all who are interested in planning of ancient towns (Gaffney *et al.*, 2000). As a result the Roman city of Wroxeter is well known to the archaeo-geophysical community and it is regarded as a significant test site for new equipment, novel applications and the refinement of methodology. The largest and most complete survey at the site, which forms the basis for the detailed analysis of the town present in this volume, was undertaken using magnetic devices called fluxgate magnetometers (see below for details). While this survey was started in 1995, it was conducted over a number of years and was the amalgamation of two geophysical groups; significant survey at Wroxeter had preceded this work and, indeed, continues at a pace.

That campaign withstanding, other more directed geophysical events have taken place at Wroxeter. As long ago as 1975 staff from English Heritage's Ancient Monuments Laboratory (AML, now Geophysics Section) surveyed part of the eastern defences (at grid reference SJ 570 087). The survey was conducted in an effort to establish the presence, or otherwise, of a gateway through the defences at that point prior to the excavations carried out by Stephen Johnson (Bartlett, 1975; Johnson and Ellis 2006, 13). Although 'strong' responses were identified the results were considered to lack the definition required to establish an answer to the question regarding the gateway. While magnetometry and resistance were the two proven techniques used in that work, the methodology of the survey was not comparable to those employed in later years as increasing measurement density has subsequently become a common factor over the years. A consequence of the work was that magnetometry emerged firmly as the favoured technology for investigation at the site and this situation has essentially remained true to the present day. One reason for this was the novel data collecting technique that had been developed by members of the laboratory and which enabled results to be plotted in the field on a chart recorder (Clark and Haddon-Reece, 1973). In later years the collection strategy was to be re-defined with on-board data-loggers incorporated into new commercially available geophysical devices.

Small-scale tests were infrequently undertaken at Wroxeter in the next twenty years or so after the AML work. Towards the end of that period geophysical prospecting had become embedded in everyday archaeological work in the UK. The principal reasons for this include the availability of better-quality instruments, the capacity to digitally record geophysical data and the rise of developer-funded evaluation archaeology that embraced magnetometry in particular into a battery of quick and cost-effective techniques (Gaffney and Gater 1993). A result of these technical and application changes meant a great increase in the number of surveys, and it is likely that in excess of 500 surveys are now undertaken each year in the UK alone, covering many square kilometres of land. The most frequently used geophysical technique uses fluxgate technology at its core, and these instruments have been dubbed 'the workhorse' of archaeological geophysics (Clark 1990).

However, magnetometer surveys, as with all geophysical and remote-sensing techniques, do have several limitations and one of these relates to the 'visibility' of anomalies. Geophysical anomalies are regarded as the measured product of the *contrast* between a feature and the matrix into which it is embedded. Evidently the contrast that is measured is different for the various geophysical techniques and in the case of the magnetometer it results from the differences in magnetic properties between the features and the surrounding soil (Aspinall, Gaffney & Schmidt 2008). During the early 1990s a number of surveys were undertaken in the vicinity of the Roman town for 'evaluation' purposes relating to planning, but few had particularly positive results. The general lack of encouraging responses can be attributed to local soil conditions, which are often found to be Boulder Clay and Morainic Drift ('Mercian Mudstone') over Permian and Triassic Sandstones. Frequently it has been suggested that magnetic surveys over Boulder Clay provide, at best, only a partial picture of the buried archaeology due to an inability to produce a large enough magnetic contrast between the features and the soil in which they reside (David *et al.* 2008). It can be deduced that if strong magnetic anomalies are present in the area local to Wroxeter, then it is the amount or type of archaeological activity that is the overriding factor on this occasion rather than a contribution from the geological or pedological background. Undoubtedly some activities involving high temperature or some 'industrial processes' always produce some magnetic contrast, but these events are likely to be unrepresentative of typical archaeological activities.

It is more realistic to expect low contrast conditions i.e. very weak magnetic signals, in the Wroxeter area. To understand the problems that are linked to low contrast response for the definition of buried archaeological features, one must consider the results obtained at the nearby archaeological site of Whitley Grange (Gaffney and White 2007, 97) and the pre-excavation survey that was undertaken there (GSB 1995). Although the geophysical survey was primarily undertaken to enable a successful excavation strategy to be formulated, the techniques were also envisaged to be part of a series of geophysical surveys in the hinterland of Wroxeter. At Whitley Grange both magnetometry and resistance data were collected, but the results were archaeologically very disappointing. The resistance technique, which is usually very good at defining stone structures simply did not locate any archaeological remains at the site, while the magnetometer only indicated the strongly enhanced readings over what turned out to be part of heating system of the bath house (GSB 1996). These data reflect the many poor results from other surveys in the locality. Very few have produced interpretable or even definable archaeological anomalies although in excavation, it proved that the poor results at Whitley Grange were caused partly by differential burial of the remains due to colluvium (Gaffney and White 2007, 95-142).

The results from a number of surveys in the area can be accessed via the English Heritage Geophysical Database (http://sdb2.eng-h.gov.uk/). It is evident that the sites in the hinterland of Wroxeter have produced very low contrasts between the expected targets and the surrounding soil. This revelation has severe implications for survey in the area around the town; however, within the town nearly every geophysical survey has provided useful archaeological results. The reason for this disparity is due to the highly altered nature of the soil within the town. Several centuries of intense human intervention has changed the soil in such a way as to create strong contrasts that are readily measured using commercially available instruments.

1.5 TECHNIQUES USED AT WROXETER

There are many ground based geophysical techniques that can be used for detecting shallow buried features. A list of those techniques that have been used at Wroxeter can be seen in Table 1.2. The basis of the techniques can be understood by reference to theory that encompasses classical through to quantum physics and the breadth of novel applications indicates that Wroxeter has become an enduring geophysical experiment. A brief explanation of the basis of the techniques is required to understand the significance of the work.

Magnetometry

Magnetometry is the most frequently used geophysical technique for archaeological purposes. Magnetometers measure very small changes in the earth's magnetic field that are a result of contrasts between the magnetic properties of archaeological features and the soil that surrounds them. The contrasts can be linked to remnant (permanent) or induced (temporary) magnetization. Thermally induced remnant magnetization is acquired by an alteration resulting from heating the material above the Curie Temperature. The value of the Curie Temperature is variable due to the minerals present in the material; it is typically about 600°C. As the material cools below the Curie Temperature it acquires a strong and permanent magnetization. Classically, this is the cause of the magnetic anomalies associated with kilns and other fired or industrial remains and is likely to be the cause of the anomalies identified at Whitely Grange. While the first practical magnetometers were built to detect thermally induced remnant signals from kilns buried along an upgrade of the A1 road near *Durobrivae*, one of the additional benefits was that weaker, induced signals could also be identified and these were linked to the fills of pits and ditches (Aitken 1986).

The second process to engender a magnetometer anomaly is significantly different from permanent magnetization produced by high temperatures. Induced magnetization is a temporary phenomenon that results from a contrast in the magnetic susceptibility of the material with respect to the surroundings. A magnetic field is required to induce this property and in the case of *passive* magnetometers the earth's field is sufficient. The strength of the magnetization is a result of how magnetically 'enhanced' the material is, and this depends upon a great number of factors. There are, however, five pathways that are generally assumed to increase the magnetic susceptibility of a material.

- Burning — Le Borgne (1955, 1960)
- Organic 'fermentation' or 'microbially mediated' — (Linford 2004)
- Magnetic bacteria — (Fassbinder *et al.* 1990)
- Importation of enhanced material (manuring) — (Weston 2002)
- Soil formation processes (pedogenesis) — Maher and Taylor (1988).

Essentially, while natural causes may be encountered for remnant or induced magnetization, they are to a great extent influenced by general anthropogenic activity However, the link between strength of signal and archaeology is neither linear nor only linked to the production of strongly magnetized or enhanced magnetization of features or fills. At a site such as Wroxeter the magnetic signal measured at the surface often results from many physically close features whose magnetic signals are additive. Also some materials (e.g. sedimentary rock) that are often used for building house and field walls reveal very low levels of

Technique	Type	Coverage	Feature usually detected
Magnetometry	Fluxgate, Caesium Vapour, SQUID	Area and Traverse	Ditches, pits and fired / industrial remains
Resistance	Twin-Probe, Square Array	Area	Walls, ditches and made surfaces
Resistivity	Electrical Imaging	Traverse	Deeply buried strata
GPR	Various antennas	Area and Traverse	Equivalent to resistance technique, but possibly greater resolution at depth
Electromagnetic	Conductivity, magnetic susceptibility and 'metal detector	Area, Traverse and 'Random'	Depending on type of instrument – walls, ditches, 'activity' and artefacts
Seismic	Refraction	Traverse	Deeply buried strata and some discrete large features

Table 1.2: Geophysical survey techniques used at Wroxeter.

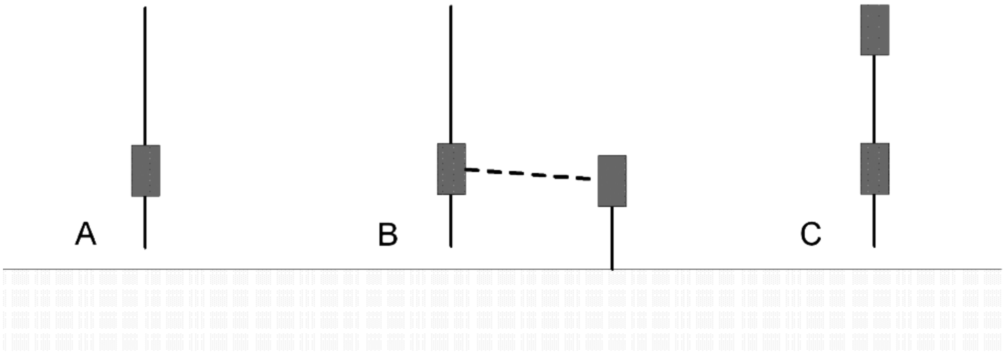


Figure 1.4: Different modes for magnetometers: (A) single, (B) differential and (C) gradiometer. After Aspinall *et al.* 2008.

induced magnetization and contrast negatively with the relatively high background soils within a town. As a result magnetometers are required to measure very small changes of both positive and negative values; these are often in the range of a few nanoTesla (nT) or less.

The main types of magnetometers that have been used at Wroxeter are fluxgate and caesium vapour instruments. The former measure a particular component of the earth's field, invariably the vertical, while the latter measure an approximation of the total field (i.e. not component specific) and are sometimes called 'intensity' instruments. A little knowledge regarding the variation of the Earth's magnetic field will suggest that the vertical field component and the total field intensity vary independently depending on the location of the survey on the Earth (Aspinall *et al.* 2008). In the UK the difference in response between the two measurement types has been found to be very small and the results from Wroxeter, see below, clearly support this assertion. However, the instruments themselves exhibit significant differences in that the caesium vapour are inherently more sensitive to small changes in the Earth's magnetic field (Linford *et al.* 2007).

The fluxgate systems used for archaeological purposes always monitor the vertical component of the local, or ambient, earth field. In fact two fluxgate sensors (FM) are mounted vertically, c in Figure 1.4, within the same housing and separated by a set distance, usually 0.5 or 1.0m. This is usually referred to as 'gradiometer' mode (Figure 1.4, 'C'): the upper is predominantly affected by the earth's field (many thousands of nT in strength, but which varies in a random fashion) and the lower is more affected by the variation that results from the buried archaeology (often a few nT in strength) on the earth's field. By subtracting one from the other an estimate of the response due to the buried material can be obtained. If there is no archaeology, or any other magnetic body, present then there will be no difference between the two readings and a value of zero will be registered. As a result all fluxgate data sets are centred on a common value of 'zero'.

The caesium vapour (CV) sensors are more adaptable as they can be used as single sensors, gradiometers similar to the FM or with reference to a fixed sensor which is usually termed differential or 'variometer' mode (Figure 1.4). Frequently CV data have been collected as a 'gradiometer', although it is certainly acceptable to undertake survey in the other modes and the differential option has become more acceptable in archaeological applications. The major benefit for using the CV type of magnetometer is that it is inherently more sensitive than the FM instruments. However, at Wroxeter, the magnetic signals are strong, by comparison to those from less intensively settled sites nearby, and the sensitivity is not a dominant factor in sensor selection. Survey beyond the confines of the city, for example on sites such as the Whitley Grange villa, may benefit from the use of more sensitive sensors.

Perhaps of greater methodological interest at Wroxeter is the density of data measurements using magnetometers rather than the sensitivity of the instruments. As has already been discussed the whole of the available land within the town has been mapped in detail using FM instruments. The instrument that was used for this exercise is the Geoscan Research FM series with a 0.5m separation between the two fluxgate sensors and data were collected at 0.25m intervals along traverses that were 1.0m apart (Figure 1.5). Although these instruments can collect higher pre-defined sampling densities, they are not as flexible as the CV instruments with respect to increasing the in-line data collection. Also, as the CV sensors are modular it is easier to put a great number on a non-magnetic cart and reduce the distance between traverses. One downside of the CV sensors is that they are generally more expensive than FMs and as a result the latter are the most widely used in academic and commercial work in Britain.

Fluxgate Gradiometry – the geophysical base map of Wroxeter

As noted above the fluxgate magnetometer has been the most frequently and widely used technique at Wroxeter. The early surveys within the town are characterized by small-scale, problem-specific data collection. It is probably fair to suggest that they were not very successful and merely indicated the potential of the technique at the site. Several factors can be recognized for the lack of success:

Figure 1.5: Members of the AML team carry out the FM gradiometry survey at Wroxeter, (Photo R White)

1. Relatively insensitive magnetometers. The introduction of the Geoscan Research FM series of magnetometers have been identified as the first 'modern' instrument and the FM18 (production date: 1987) with its integrated data-logger heralded commercially viable geophysical survey for archaeological purposes.
2. Coarse sampling density. Much of the early magnetometer data was hand logged at 1.0 x 1.0m intervals and the advent of the FM18 with logging facilities and a sample trigger effectively ushered magnetometer data into the research agenda at Wroxeter.

Perhaps the first serious attempt at a large area survey at Wroxeter was by Katherine Roberts, a, PhD student from the University of Cambridge; Roberts (1994) documents both magnetometer and resistance survey within the town. Although the data were collected to identify suitable processing steps in the emerging field of data analysis, there was an archaeological question relating to the town that was to be answered, specifically the detection of inhabited areas in what was assumed to be a sparsely occupied part of the town, and the detection of a road that could be seen on aerial photographs trending towards the defences in this area (Esmonde Cleary *et al.* 2006, 7). Approximately 4ha of magnetic data was collected at relatively high data intensity, and this led to an interesting process of analysis associated with the then emerging concepts of image processing / classification rather than research into the site itself. This work identified magnetometry as a technique that would produce significant archaeological benefits at Wroxeter.

Between June 1995 and 1999 fluxgate gradiometer data was collected over the whole of the available area within the town. Initially a pilot survey was undertaken in the core of the town. The location was in sharp contrast to the majority of the previous surveys that concentrated on the entrances through the defences. It was hoped that some of the major elements evident on the aerial photographs for the site could be located and this would provide the stimulus to expand the survey toward the perimeter of the town. The pilot survey covered what was deemed to be Field 1 for the geophysical project (*insulae* VI, IX, X-XIII). This field lies to the south of the excavated baths complex and it was evident from the AP evidence that a number of stone-built high-status Roman buildings were present (*see* Chapter 3).

During this initial survey, which covered the whole of the field, a remarkably clear plan emerged including roads, building and other anthropogenic anomalies. Interestingly, the stone structures produced relatively strong negative gradiometer anomalies. This response, although not unique, was at the time rare on UK soils. It is produced by magnetically low building material embedded within settlement soils of high magnetic susceptibility. It soon became apparent that the magnetic survey did not simply replicate the aerial information, but added considerable detail. The pilot study effectively demonstrated that magnetometry would not only be a valid technique to assess those areas of the city shown by aerial evidence to contain significant archaeological features and deposits, but would also aid investigation of those areas previously thought to be devoid of Roman structures. It was hoped that the magnetic data would be able to test the concept of the 'garden' city and that an analysis at the street by street level could be achieved.

Figure 1.6: Overall Fluxgate Magnetometer (FM image from Wroxeter). Produced by EH using EH and GSB data, after Gaffney *et al* 2000.

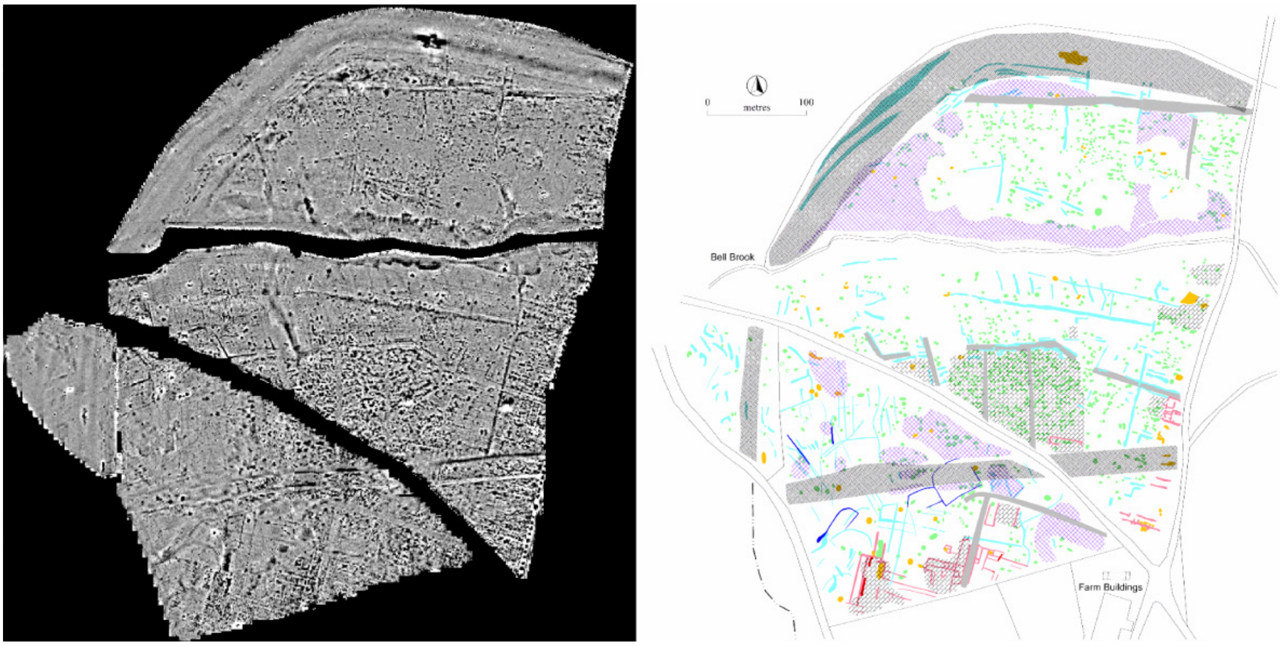


Figure 1.7: Wroxeter, northwest quadrant of FM survey. White = -7nT, Black = +7nT

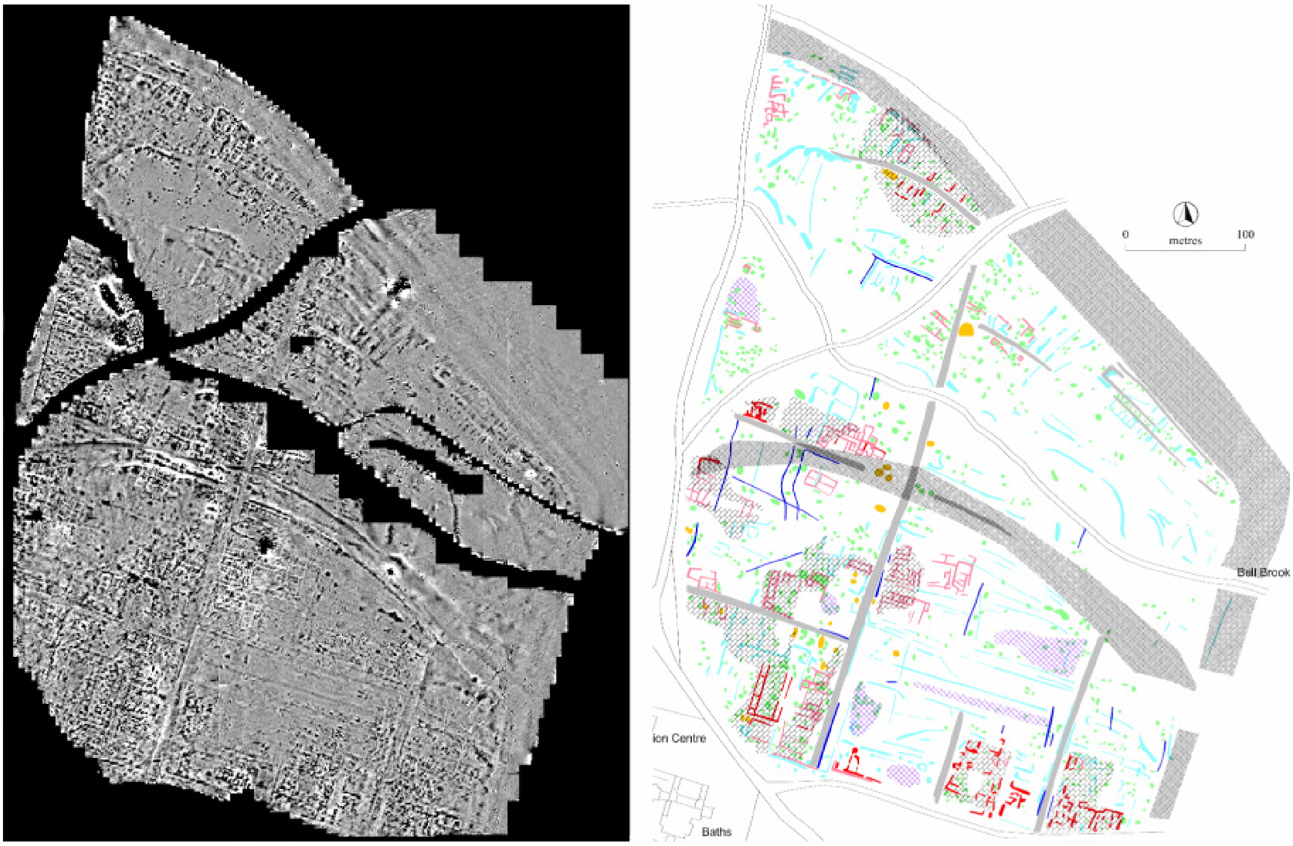


Figure 1.8: Wroxeter: northeast quadrant of FM survey. White = -7nT, Black = +7nT

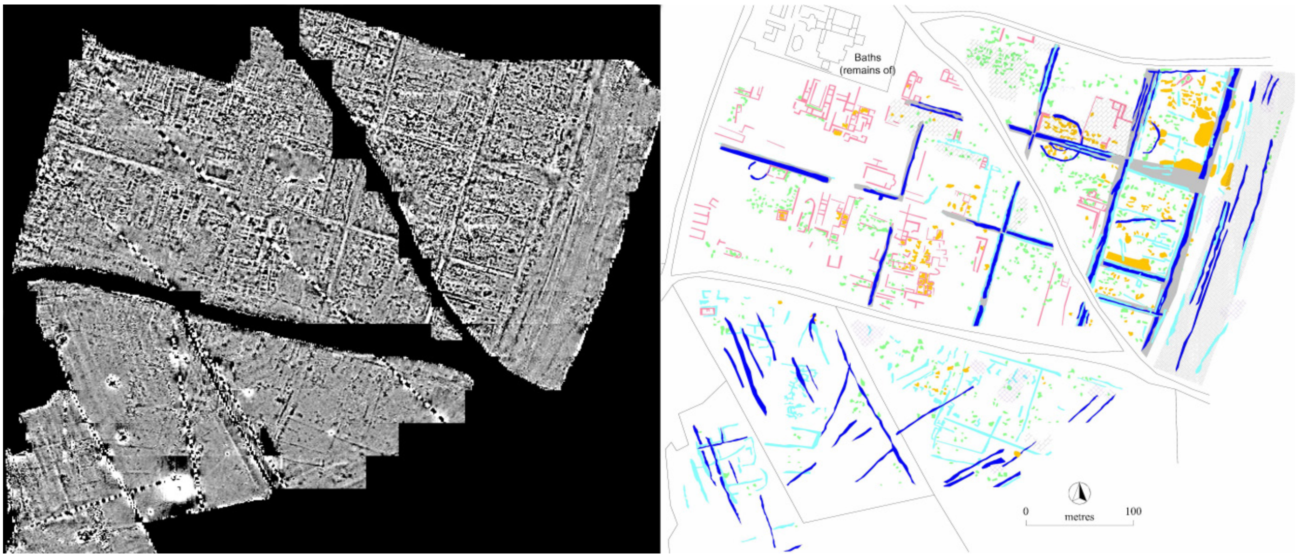


Figure 1.9: Wroxeter: southeast quadrant of FM survey. White = -7nT, Black = +7nT

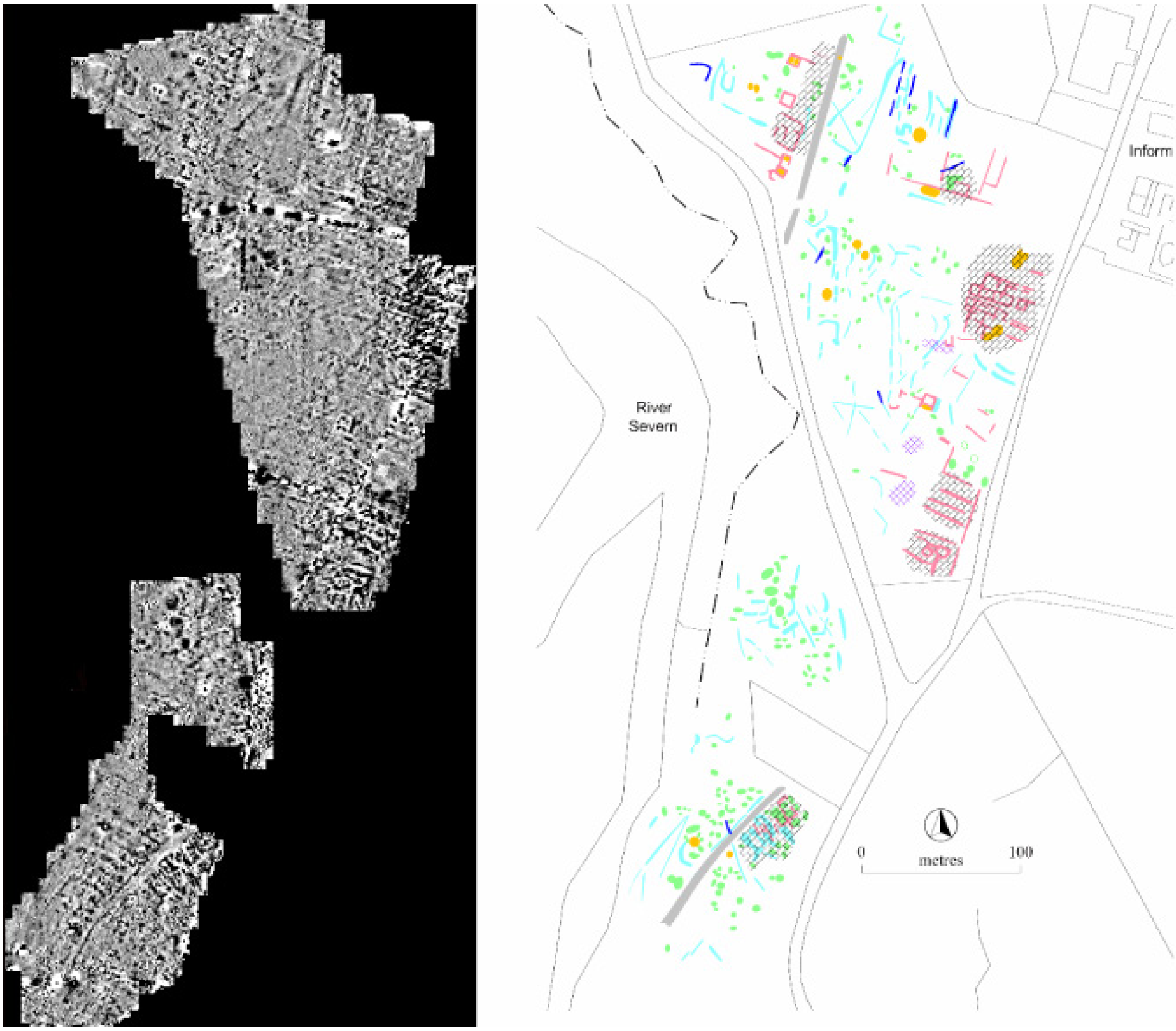
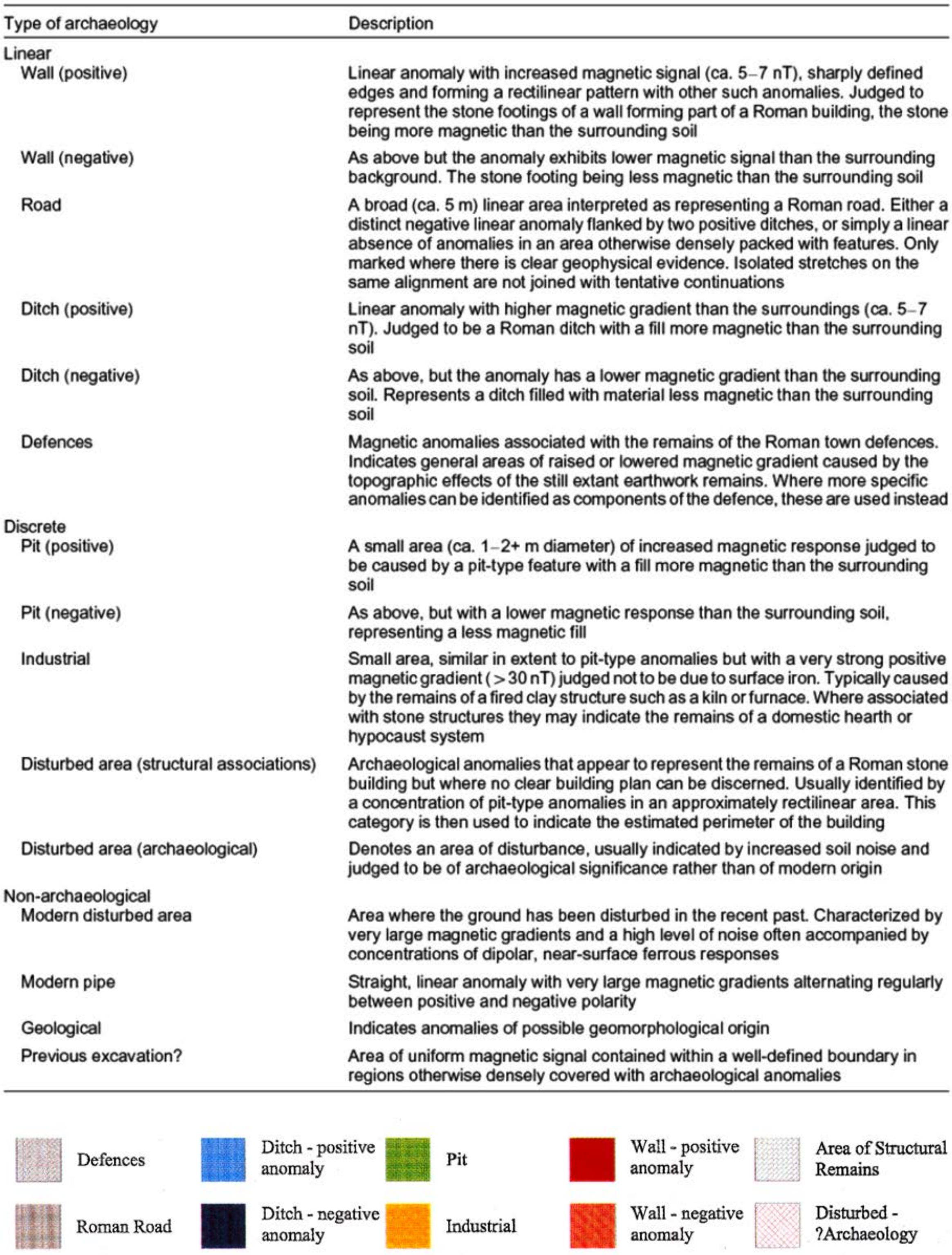


Figure 1.10: Wroxeter: southwest quadrant of FM survey. White = -7nT, Black = +7nT



Type of archaeology	Description
Linear	
Wall (positive)	Linear anomaly with increased magnetic signal (ca. 5–7 nT), sharply defined edges and forming a rectilinear pattern with other such anomalies. Judged to represent the stone footings of a wall forming part of a Roman building, the stone being more magnetic than the surrounding soil
Wall (negative)	As above but the anomaly exhibits lower magnetic signal than the surrounding background. The stone footing being less magnetic than the surrounding soil
Road	A broad (ca. 5 m) linear area interpreted as representing a Roman road. Either a distinct negative linear anomaly flanked by two positive ditches, or simply a linear absence of anomalies in an area otherwise densely packed with features. Only marked where there is clear geophysical evidence. Isolated stretches on the same alignment are not joined with tentative continuations
Ditch (positive)	Linear anomaly with higher magnetic gradient than the surroundings (ca. 5–7 nT). Judged to be a Roman ditch with a fill more magnetic than the surrounding soil
Ditch (negative)	As above, but the anomaly has a lower magnetic gradient than the surrounding soil. Represents a ditch filled with material less magnetic than the surrounding soil
Defences	Magnetic anomalies associated with the remains of the Roman town defences. Indicates general areas of raised or lowered magnetic gradient caused by the topographic effects of the still extant earthwork remains. Where more specific anomalies can be identified as components of the defence, these are used instead
Discrete	
Pit (positive)	A small area (ca. 1–2+ m diameter) of increased magnetic response judged to be caused by a pit-type feature with a fill more magnetic than the surrounding soil
Pit (negative)	As above, but with a lower magnetic response than the surrounding soil, representing a less magnetic fill
Industrial	Small area, similar in extent to pit-type anomalies but with a very strong positive magnetic gradient (>30 nT) judged not to be due to surface iron. Typically caused by the remains of a fired clay structure such as a kiln or furnace. Where associated with stone structures they may indicate the remains of a domestic hearth or hypocaust system
Disturbed area (structural associations)	Archaeological anomalies that appear to represent the remains of a Roman stone building but where no clear building plan can be discerned. Usually identified by a concentration of pit-type anomalies in an approximately rectilinear area. This category is then used to indicate the estimated perimeter of the building
Disturbed area (archaeological)	Denotes an area of disturbance, usually indicated by increased soil noise and judged to be of archaeological significance rather than of modern origin
Non-archaeological	
Modern disturbed area	Area where the ground has been disturbed in the recent past. Characterized by very large magnetic gradients and a high level of noise often accompanied by concentrations of dipolar, near-surface ferrous responses
Modern pipe	Straight, linear anomaly with very large magnetic gradients alternating regularly between positive and negative polarity
Geological	Indicates anomalies of possible geomorphological origin
Previous excavation?	Area of uniform magnetic signal contained within a well-defined boundary in regions otherwise densely covered with archaeological anomalies

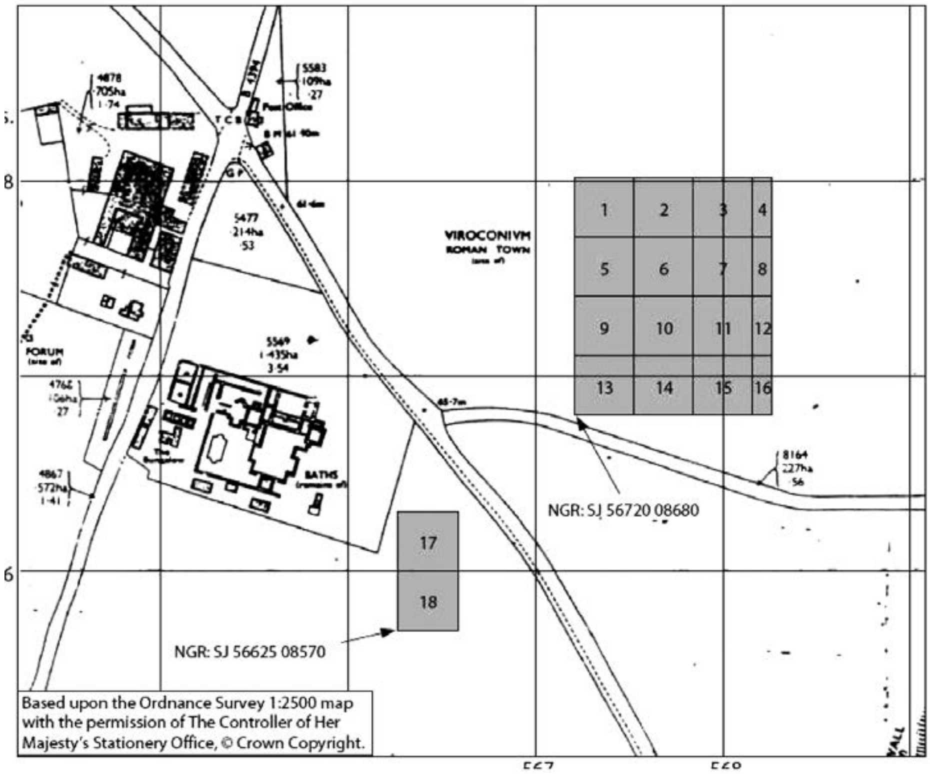
▨	Defences	🟦	Ditch - positive anomaly	🟩	Pit	🟥	Wall - positive anomaly	▨	Area of Structural Remains
▨	Roman Road	⬛	Ditch - negative anomaly	🟧	Industrial	🟥	Wall - negative anomaly	▨	Disturbed - ?Archaeology

Table 1.3: Anomaly definition within the Wroxeter magnetometry data and visual key to the interpretation of the data. After Gaffney *et al.* 2000

Subsequently the whole of the then available area was surveyed using Geoscan Research Fluxgate Gradiometers. The details of the project have been extensively documented elsewhere; the whole of 2000 volume 7(2) of the journal *Archaeological Prospection* was dedicated to 'Non-invasive Investigations at Wroxeter at the end of the Twentieth Century' and the most relevant article relating to this section is Gaffney *et al.*, 2000. Following on from the pilot study, magnetometer data were collected on traverses separated by 1.0m and measurements were taken at 25cm along each traverse. The survey covered approximately 70.2ha, which was subdivided into 20 x 20m blocks for data collection and which were oriented on the National Grid using a Trimble GPS system (Barratt *et al*. 2000). A total of 15 modern fields were wholly or partly surveyed and almost 3 million data points were collected. Two geophysical teams undertook this work; the Geophysics Section of English Heritage and GSB Prospection Ltd. Due to financial and logistical reasons it was not possible to undertake the survey in a single survey visit, and the process of data collection and analysis was spread over four years.

The summary image was published in the 2000 *Archaeological Prospection* article (Figure 1.6).

Key to the success of the project is not just the image of the magnetic variation across the town but the classification of magnetometer anomalies; it was obvious from the early work that an extensive, but essentially archaeological, list of interpretation groups or classes would be necessary for this survey. It was agreed in advance of the detailed data analysis that the interpretation would be divided into three sections; Linear (six sub-groups), Discrete (five sub-groups) and Non-archaeological (four sub-groups). Table 1.3 is a description of the classes. At the practical level each survey group checked the interpretation of the other group and as a result a consistent level of anomaly recognition and classification was reached. The agreed interpretation for each survey area was digitized and saved in DXF vector format prior to importation into GRASS GIS, and later ESRI ArcView, for final analysis and visualization. It is this data set that largely drives the extended re-interpretation of the classic aerial photographs from this site. For convenience the data have been divided into four blocks to permit their visualization and interpretation (Figures 1.7-10).



Based upon the Ordnance Survey 1:2500 map with the permission of The Controller of Her Majesty's Stationery Office, © Crown Copyright.

Figure 1.11: Location of Fassbinder's CV surveys.

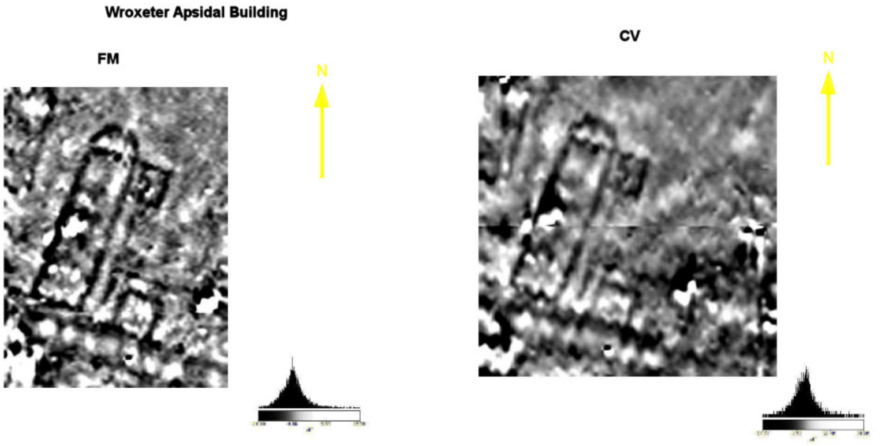


Figure 1.12 Apsidal building in *insula* VI. FM on left, CV on right. Source EH and Fassbinder

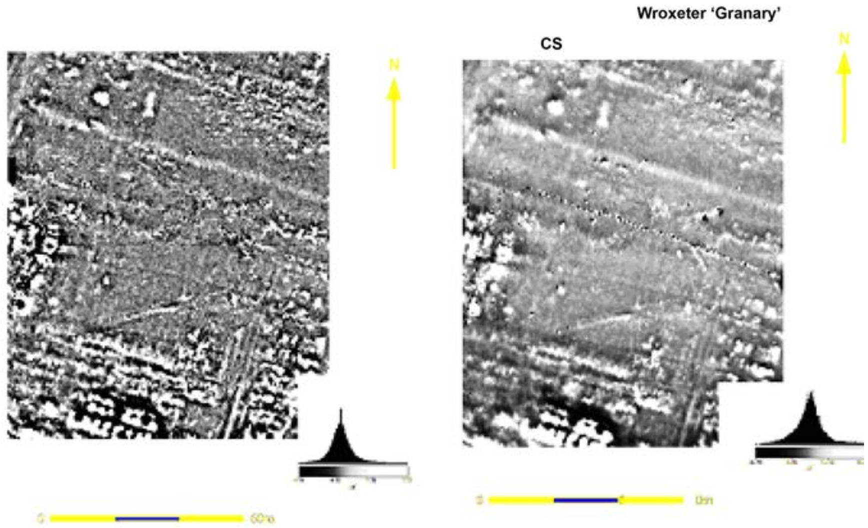


Figure 1.13 Granary in *insula* III. FM on left, CV on right. Source EH and Fassbinder

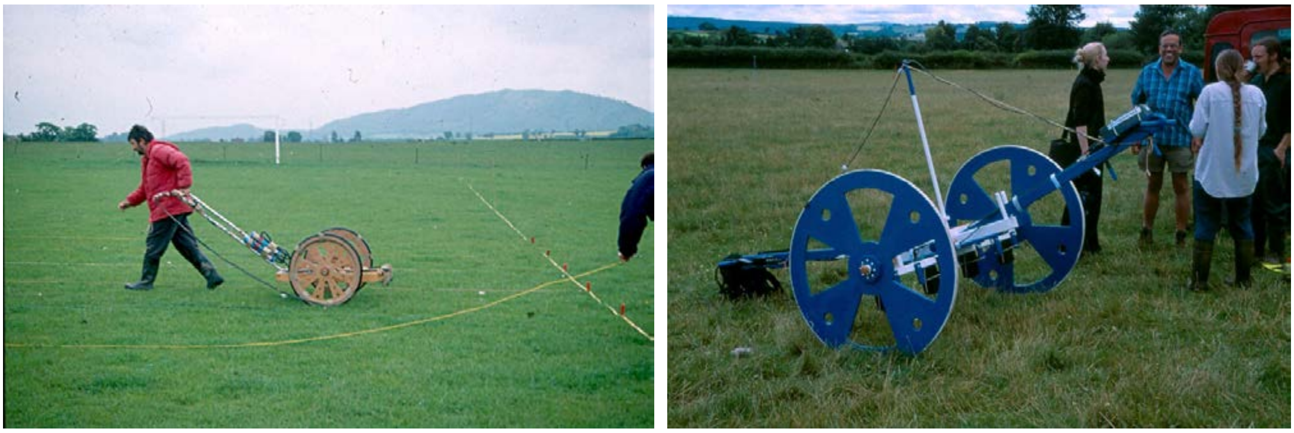


Figure 1.14: Novel caesium vapour magnetometers at Wroxeter: left Joerg Fassbinder, right, Archaeophysica. (Photos R White)

Figure 1.15. Comparison of magnetometry surveys over *insulae* XII and X. The Archaeophysica CV survey is above, the original FM survey below. The diagonal strip is a cast-iron water pipe. Note how the apparent apse on the building immediately above the pipe vanishes on the CV survey. This building is the so-called church (see Chapter 2). Source Archaeophysica

The Use of Novel Magnetometers at Wroxeter

A cursory glance at the image from the initial Fluxgate Gradiometer survey is filled by an array of different types of anomalies representing many aspects of city life during the later Roman period. A consequence of this is a recognition that the town can be used for testing unusual or novel magnetometers. During the lifetime of the present project three noteworthy events can be documented.

Caesium Vapour Sensors

During May 1997 Joerg Fassbinder from Bayerisches Landesamt für Denkmalpflege Munich, Germany was invited by English Heritage (EH) to survey with a hand-held Scintrex Caesium Vapour **(**CV) device at Wroxeter. This formed part of a series of tests on CV technology by EH that had started the previous year at Stonehenge Cursus. At Wroxeter two areas were surveyed covering a total of 1.4 ha of land (Figure 1.11). The CV instrument was set up in a similar format to the original fluxgate survey i.e. two sensors in gradiometer mode. During this research event it was decided to increase the sampling intensity for the data collection to 0.25 x 0.5m i.e. an additional traverse was collected by comparison the original fluxgate data collection. In order to ensure compatibility both CV areas were resurveyed using the Geoscan FM gradiometers at the increased sampling density.

The smaller of the two areas (SW corner at NGR: SJ 56625 08570) was over the so-called apsidal building identified during the original pilot study in Field 1(=*insula* x), while the larger area, the so called ‘granary’, is in Field 5 (= *insula* III) (SW corner at NGR: SJ 56720 08680). (Comparing the two datasets it is evident that the CV and FG data are highly comparable Figures 1.12; 1.13). However, the positional accuracy of the former was not as good as the latter and as a result there remains a significant amount of shearing over some of the anomalies. While the presumed superiority of CV instruments (e.g. Becker 1995) cannot be justified from these surveys, this event indicates a willingness to use Wroxeter as an experimental site, particularly to challenge the prevailing techniques.

In 2004, as part of National Archaeology Day, a team from Archaeophysica collected more CV data in Field 1, but utilized a base station to monitor the diurnal variation and this information was then used to correct the two single sensors that were positioned adjacent to one another on light-weight cart. This mode of employment is usually referred to as dual or duo sensor mode, which is extremely efficient as it allows two traverses of data to be collected at one time. As a result of the pre-processing the total magnetic field which resulted from the buried archaeology was calculated. This data set was collected at an even higher density than the Fassbinder data discussed above. The traverse interval was 0.5m but the sampling rate was increased so that readings were collected about every 0.15m. As can be seen in Figure 1.15 the resultant image is sharp and, while the majority of the image is similar to the original FG image, it is likely that additional minor detail has been mapped. That there are few, perhaps no, major differences between the two data sets should not be a surprise at this latitude (Aspinall *et al.* 2008, 67). The anomalies in the town are general relatively strong and fairly extensive. The on-going debate with respect to the differences between the various types of magnetometer is usually driven by the relative sensitivity of the instruments (Linford *et al.* 2007): while there are some areas where a sensor with increased sensitivity would be effective, this part of the town is not one of them.

However, close examination of the images does reveal some areas of difference. The small scale variation suggests that potentially there are a number of factors at play here including:

- Differences in sampling intensity (approximately three times as many readings were collected using the CV in a given area);
- Differences in transect orientation;
- Slight differences in total field anomalies and vertical gradient anomalies due to position on the Earth;
- Different processing strategy for each technique;
- Different plotting levels / and possibly different display algorithms.

As a result it is difficult to be certain that the measurement of the total field is ‘better’ than the original FG, as the imaging at Wroxeter is similar. It is probable that the first of the variables in the list is the most important in this case, but a research design could be conceived to consider these variables in greater detail.

Cart and GPS Driven Systems

Towards the end of 2004 the Geophysics Section of EH undertook a CV survey of Field 4, which is directly to the east of the Baths. This was in part a test of a new EH built non-magnetic cart using specially modified Scintrex SM-4 caesium vapour sensors in gradiometer mode. The measurements were collected at a rate of 10Hz (10 samples/m) along each traverse and then interpolated to a regular sample traverse interval of 0.125m (Linford *et al.* 2007). The whole of the field, about 4.5ha, was surveyed at 0.5m intervals with eight samples per metre. For this exercise the measurements were taken within a previously defined grid. It is evident from Figure 1.16 that the resultant image from this method is very sharp and amply demonstrates the benefits in good positional control of data-dense magnetic survey.

A short time later in early 2005 this field was re-surveyed with a brand new data collecting system called the Geophysical Exploration Equipment Platform, or ‘GEEP’ (Figure 1.17). This version of the GEEP was an early prototype produced by a Knowledge Transfer Partnership between University of Leicester and Geomatrix Earth

Figure 1.16: English Heritage survey of *insulae* VI, VII, XI, XIX, XX using Caesium Vapour magnetometry.

Figure 1.17: The GEEP sledge with quad bike. (Photo C. Gaffney)

Science Ltd. The sledge is pulled by quad bike or similar vehicle and can be loaded with many different types of geophysical instruments. Apart from the need for a vehicle to pull the GEEP, the other innovative part of the method was the differential global positioning system (dGPS) that guides and logs positional information for the various geophysical data: effectively this was the first grid-less area survey at the site using a geophysical technique. Although many different types of data can be collected simultaneously with the GEEP, at Wroxeter the Leicester team configured the platform with an array of CV sensors and they subsequently surveyed the three fields in the southeast quadrant. They spent the majority of the time in Field 4 where they deployed the sensors in three different modes and repeated the survey with each set up.

By comparison to the previous EH CV data, and even the original lower spatial density fluxgate survey, it is clear that the GEEP data is not as good quality (Figure 1.18). The major reason for this is the relatively low grade GPS system used was not entirely suitable for the speed of data collection or the small lateral changes in magnetic signal that are common on archaeological sites. It must be remembered that the GEEP was essentially specified for mineral or similar applications that often require less positional accuracy due to the spatially large anomalies that need to be mapped. Additionally, the survey was undertaken to prove the system rather than extend the knowledge of the site. However, this illustrates the value of the original fluxgate survey and Wroxeter as an important resource for the testing of novel or new instrumentation. Perhaps the most important aspect of this event is that the GEEP pointed clearly towards fast data collection using GPS for grid-less geophysical survey. In a three hour block the GEEP surveyed about 6ha of Wroxeter and collected over 500,000 data points. While it was obvious that real time, highly accurate GPS is required to make this system function effectively at the archaeological level, it was also clear that this upgrade was relatively straightforward. A technical discussion of the results from Wroxeter can be found in the final report on the GEEP project, which can be accessed at:

http://www.sustainableaggregates.com/docs/theme2/miro_ma_3_1_001.pdf

In late 2006 Wroxeter became the test bed for a fluxgate system that utilized high accurate, real-time GPS as the basis for both navigation and measurement position and the results are partly discussed in Gaffney *et al.* (2008). Although the sensors use fluxgate technology they are different from the Geoscan Research sensors in a number of ways. Foerster, the manufacturer, has produced a sensor that requires no user input before field use; the sensors are simply attached to the data logger and are then ready to collect data.

The instrument is essentially modular in that many sensors can be attached to an appropriate data logger and therefore

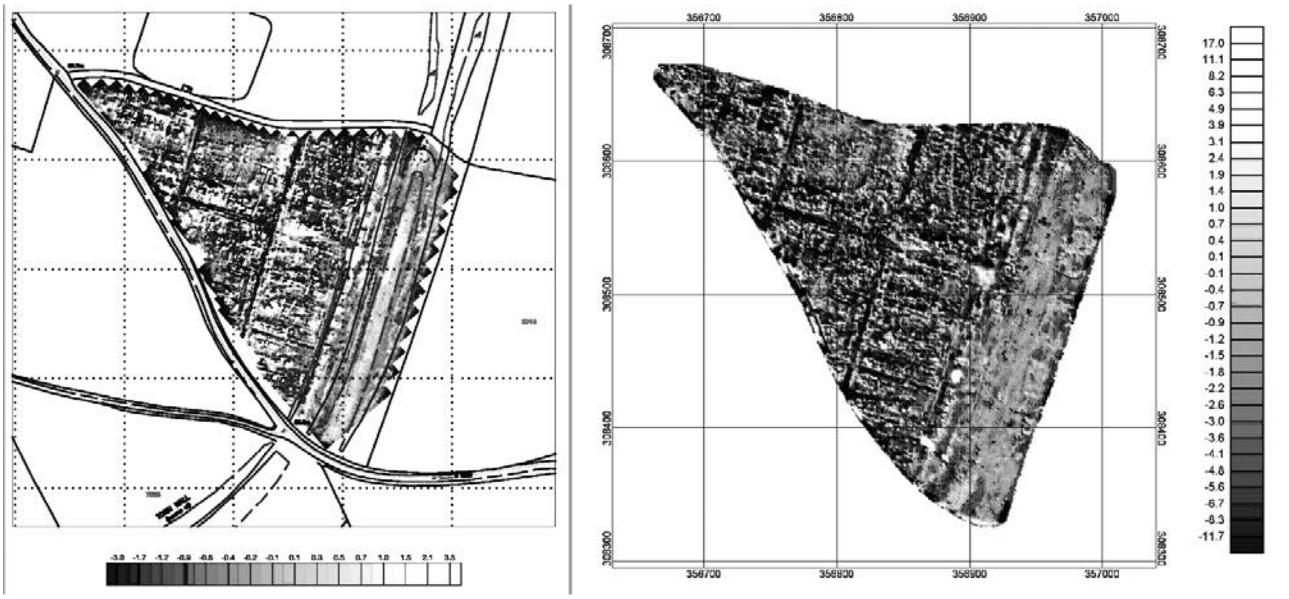


Figure 1.18: English Heritage (left) and GEEP (right) CV surveys of *insulae* VI, VII, XIX, XX, XXI. The EH data are collected using a traditional grid, while the GEEP data used GPS location.

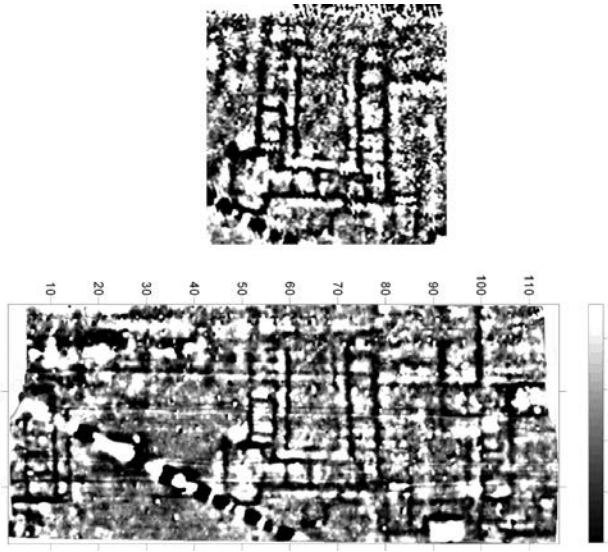


Figure 1.19: *Insula* IX, Foerster Ferrex data compared to FM survey (above).

the operator has the option to increase data density or spatial coverage by varying the lateral distance between the sensors. In the Wroxeter test a non-magnetic cart was used with four probes attached to a dedicated data logger. The Foerster system was originally conceived to detect buried ordnance and therefore designed to pinpoint strong dipolar (ferrous) anomalies. Given the intended use it is not surprising that the sensitivity of the sensors is relatively poor, but in the context of a Roman town this is not a criterion that would argue against its use. Indeed, other aspects of the system are very appealing to the archaeological geophysicist; the real time GPS not only allows a grid free survey but additionally gives centimetre accuracy to each magnetometer reading (Figure 1.19). As a result, greater certainty is possible in the position of each reading, thereby reducing the need for processing and increasing the interpretational value of the data. Although the Foerster survey at Wroxeter was only undertaken as a proof of method, the results provide new, more subtle, information by comparison with the original magnetometer data. While this may be counterintuitive given the sensitivity of the sensors, the mapping of subtle variation is linked to the small (0.5m) separation between each sensor traverse.

SQUID Sensors

One other magnetometer type that has been used at Wroxeter is a SQUID (Superconducting Quantum Interference Device) developed at the Jena Institute in Germany. Although it has only been used for a day inside the town and another in a field directly to the north, it has proved a significant development. The measurements are similar to the fluxgate in that they usually measure the vertical component of the earth's field, but the sensors and the output are significantly different. In order to function the sensors must be able to super conduct that is they must have nil electrical resistance and this requires cryogenic conditions (Chwala *et al.* 2001, 2003 and Schultz *et al.* 2007). While maintaining the sensors at very low temperatures is a real practical limitation the benefits are considerable in that such devices are many times more sensitive than even the commercially produced CV magnetometers. Perhaps more important in the discussion of Wroxeter is the fact that the sampling rate is very large and that the sensors are mounted on a vehicle-pulled cart which can reach speeds of 30 mph. The cart is steered along a path indicated by a fluxgate compass and the exact position of each reading is recorded using real-time dGPS. It is important, however, to correct for the presence of the vehicle and the pitch and roll of the cart during data collection.

Two areas of Wroxeter have been surveyed by the Jena team, one covering Field 4 and the other a field just to the

Figure 1.20: SQUID array and tow-car at Wroxeter. (Photo C. Gaffney)

north of the city walls. In terms of this monograph the data collected from Field 4 are most relevant and they can be seen in Figures 1.21 and 22.

A number of points should be made regarding the display of the SQUID data. Although they measure the changes in the vertical field component, as do the FM systems, the data look significantly different. This results from the fact that the SQUID sensors are set to measure the vertical gradient of the horizontal component of the earth's field ($dB_{horizontal}/dz$), and this effectively measures a true gradient (Schultz *et al.* 2008). A consequence of this is that the response over an archaeological feature looks like a derivative of the total field response i.e. the bipolar nature of the display is highly reminiscent of fluxgate data that has been subject to a direction filter or visualized using a light source. The interpretation of the SQUID data is therefore much more complicated as it is visually often difficult to work out whether the positive or negative element is dominant. Despite this reservation regarding the display of data the apparent increase in mapping minor variations in the earth's field would be valuable were the survey extended across the town.

Perhaps one surprising and welcome outcome from the SQUID survey beyond the city walls is that clear and convincing magnetic results were obtained in that area. It should be stressed that this is not simply due to the increased sensitivity of the instrument used, but the fact that strong contrasts are maintained there. An important conclusion is that magnetic survey is worthwhile beyond the visual limits of Wroxeter. This has ramifications for how we investigate the archaeological resource beyond the city; positive results in the vicinity of the town will result in greater understanding of settlement areas that were both intensive and long lived. Given the previous work in the environs of the city the use of sensitive magnetometers could be an emerging research avenue for the low-magnetic contrast hinterland of Wroxeter.

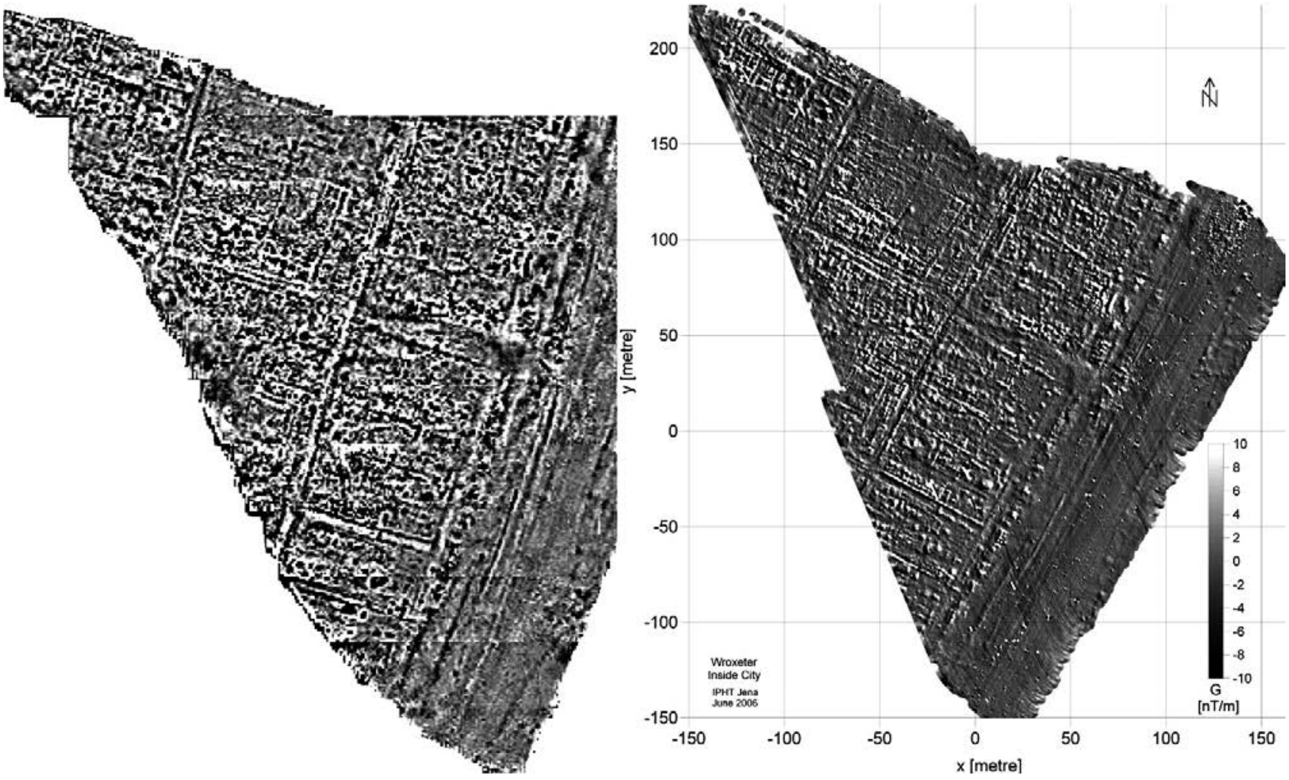


Figure 1.21: *Insulae* VI, VII, XIX, XX, XXI as shown on the original FM survey (left) and IPHT Jena SQUID survey (right).

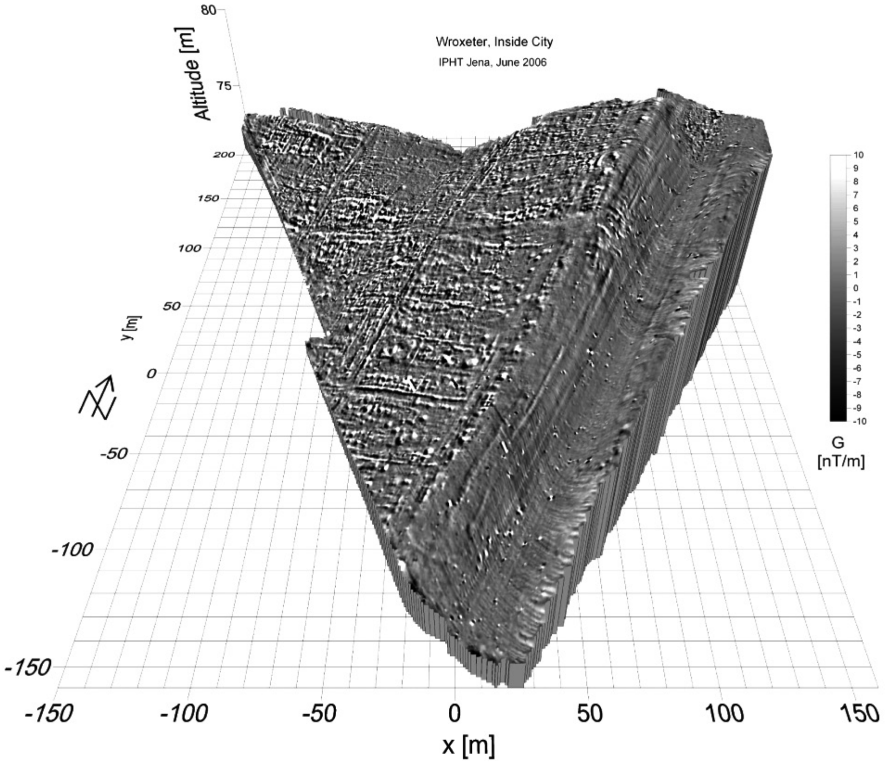


Figure 1.22: SQUID data draped over topographic model showing town ditch. Courtesy of IPHT Jena

Resistance and Resistivity

Area Survey

In Britain resistance survey has a long pedigree for archaeological prospecting, with resistance data collected as early as the 1940s (Atkinson 1952; 1963), although a variation in the method was used to map shallow remains in north America before World War II (Bevan 2000). The Wroxeter Project had a large community involvement and much of the focus for this was concentrated on area resistance which is inevitably more labour-intensive and thus lends itself to community involvement. Significant areas were covered but unfortunately the untimely death of Mr John Guite, the volunteer who coordinated this aspect of the project, resulted ultimately in the loss of the data which could not be retrieved from his computer. In part this was a consequence of the relatively simple data management facilities available at the time since all processing was carried out on stand-alone PCs with minimal capacity for secure storage. The tragic death of John Guite thus served also to demonstrate the need for fuller integration of volunteer and professional teams within projects that have such a strong community base.

The basis for area earth resistance survey is relatively straightforward. Two current probes are used to inject electricity into the ground and a further two probes are used to measure the voltage drop. Using an instrument that maintains a constant current output and measures the voltage between two points allows the earth resistance to be calculated at a given position. With reference to the geometrical arrangement of the four probes, this value can be related to the soil's resistivity (see Schmidt 2009 for a good discussion of these factors). There are many different probe arrangements (also termed arrays) that are used for earth resistance studies. Effectively the resistance is a measure of the moisture content of the ground and in the simplest of cases the spatial variation can be linked to specific archaeological forms. For example, within a Roman town stone-built structures are likely to have a low moisture content which will result in aligned, high resistance patterning. Ditches usually produce opposite results (low resistance by comparison to the surrounding soil values) as a result of the presence of moisture retaining soil. Using a sufficiently dense mesh of measurements i.e. detailed or area survey, the spatial pattern of the anomalies can be determined and an interpretation suggested.

Archaeologists have developed their own probe arrangement, the Twin-Probe array (Aspinall and Lynam 1970), which has become ubiquitous in area resistance survey. In fact there has been a realization that there has been too much reliance on not only the Twin-Probe array but also the methodological envelope within which the Twin-Probe has been deployed. While the lead geophysicist on the original Twin-Probe work has led the re-investigation of other array types (Aspinall and Gaffney 2001, Aspinall and Saunders 2005), work during the 1990s at Wroxeter was at the forefront of methodological developments of the array. A practical wheeled arrangement was tested (Dabas *et al.*, 2000), as was a multiplex system for simultaneous Twin-Probe readings at depth (Walker, 2000). Despite these advances the site at Wroxeter has not yet been subject to a complete resistance survey. In part this is a result of the success of magnetometer survey apparently leaving little unknown archaeology to be mapped. More realistically the still (relatively) slow speed of data capture is a limiting factor. However, it is likely that an area resistance survey of the whole city would be highly beneficial, especially if different depths of response could be collected at the same time. Such devices now exist (Dabas 2009) but careful planning is required to maximize the results of this type of exercise. The major limitation lies not with the technology but the well known, if little understood, problem of seasonality http://www.slideshare.net/DARTProject/the-effects-of-seasonal-variation-on-archaeological-detection-using-earth-resistance-preliminary-results-from-an-ongoing-study.

The number of area resistance surveys that have been undertaken at Wroxeter is very small and the total area coverage is similarly poor by comparison to the overall magnetometer survey. Perhaps surprisingly one of the earliest resistance surveys was not conducted using the 'standard' Twin-Probe, but with a 0.5m Square Array (Jones 1989; Esmonde Cleary *et al.* 2006, 5). The focus of the survey was the zone within the north-west (civil) defences, and this was typical of many of the early efforts and reflected a dominant archaeological research interest at the time. Other small scale efforts are known from the grey literature and they are mostly undertaken with Geoscan Research resistance meters and linked to comparative fluxgate surveys (e.g. Boyd *et al.* 1992; Latham 1995). Overall these are 'key-hole' investigations and are characterized by their small area.

Up to the point that Roberts (1994) undertook her geophysical research in Field 9 (*Insulae* XXXIII, XXXV and XXXVI) the resistance surveys at Wroxeter were simply too small to make much of an impact on the interpretation of the site. Additionally, one concern that could be discussed with respect to resistance survey is the likely depth of both topsoil and archaeological strata. It is evident from the excavations in the central part of the city that these may be several metres in depth locally (*see* Depth modeling, Chapter 3). However, during the excavations in *Insula* XXXVI (Esmonde Cleary *et al.* 2006) that followed Roberts' survey it became clear that the topsoil in the area is about 20-30cm thick and therefore the depth to the buried archaeology is well within the range of the standard 0.5m Twin-Probe that Roberts used. The images that she produced are notable primarily due to the response from the ice wedge polygons that can be seen also on the aerial photographs from this area (Baker 1992). Although there are evidently anomalies of archaeological interest in the data set, the resistance data does not show much correspondence with the Fluxgate data collected during the same event. This is presumably in part due to the influence of the underlying geology and the variation due to seasonal moisture changes and reflects many of the problems associated with this technique. However, it should be made clear that a comparison between earth resistance and fluxgate area data is not expected to find a close correlation between the two techniques' responses to the same features: each measures contrasts in different properties and therefore the images should not be identical, especially in a complex settlement site.

The two most important resistance surveys undertaken at Wroxeter were published within the same *Archaeological Prospection* volume as the main fluxgate survey. Both articles are primarily linked to the verification of new methods. In the case of Walker (2000) the results show

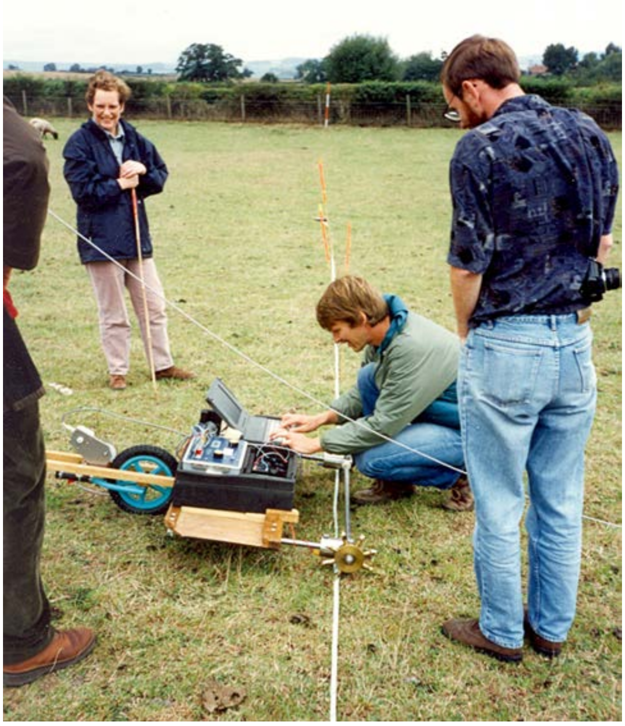
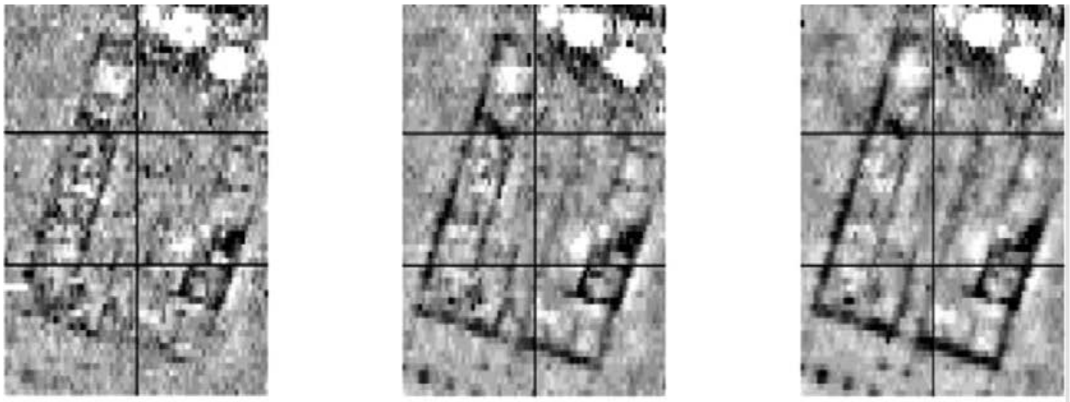


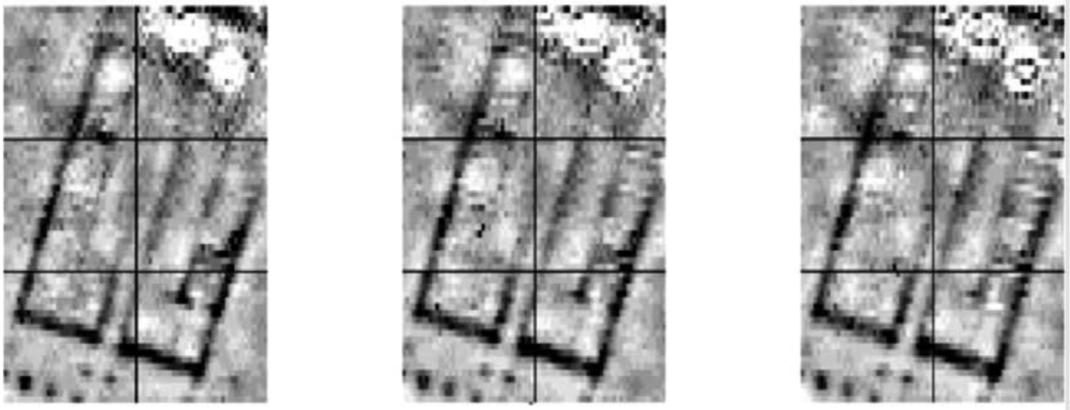
Figure 1.23: Resistivity surveys. Left: Roger Walker and the Multiplex array; right Preparing the resistivity platform with spiked-wheel array. (Photos R. White)

the use of a multiplexing probe system that is based on the conventional Twin-Probe, but captured six different separations (Figure 1.23). These were linked to increasing depths of investigation over a 40 x 60m area that had previously revealed a large stone built building within *insula* XII. The six 20m square grids were sampled at 0.5m intervals along traverses that were separated by 1m.

As can be seen in Figure 1.24 there was clear variation with presumed depth and significant detail was accrued about the building. The Geoscan Research Multiplexer has since become a standard tool in the archaeological geophysicist's toolbox despite its relatively slow rate of data capture e.g. Papadopoulos *et al.* (2006).

The second novel resistance method was promoted by a French team who used a prototype platform that included spikes within the platform's wheels that acted as probes for the Pole-Pole array (Dabas *et al.* 2000). This type of array is a special variation of the Twin-Probe that reduces


0.25 m Twin
0.5 m Twin
0.75 m Twin


1.0 m Twin
1.25 m Twin
1.5 m Twin

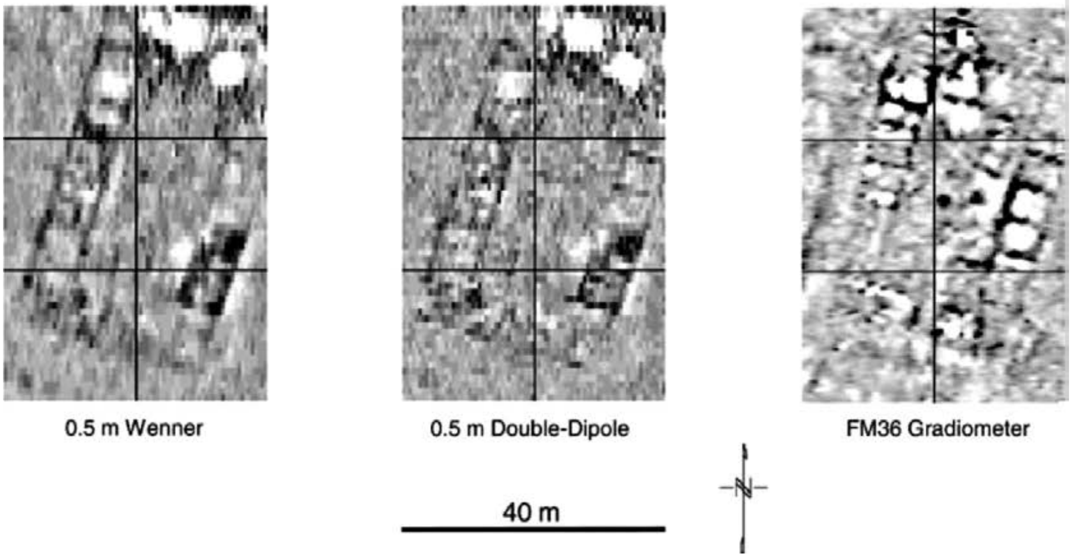

0.5 m Wenner
0.5 m Double-Dipole
FM36 Gradiometer

Figure 1.24: Multiplex resistivity displays over building on *insula* XII demonstrating different arrays. Courtesy R. Walker

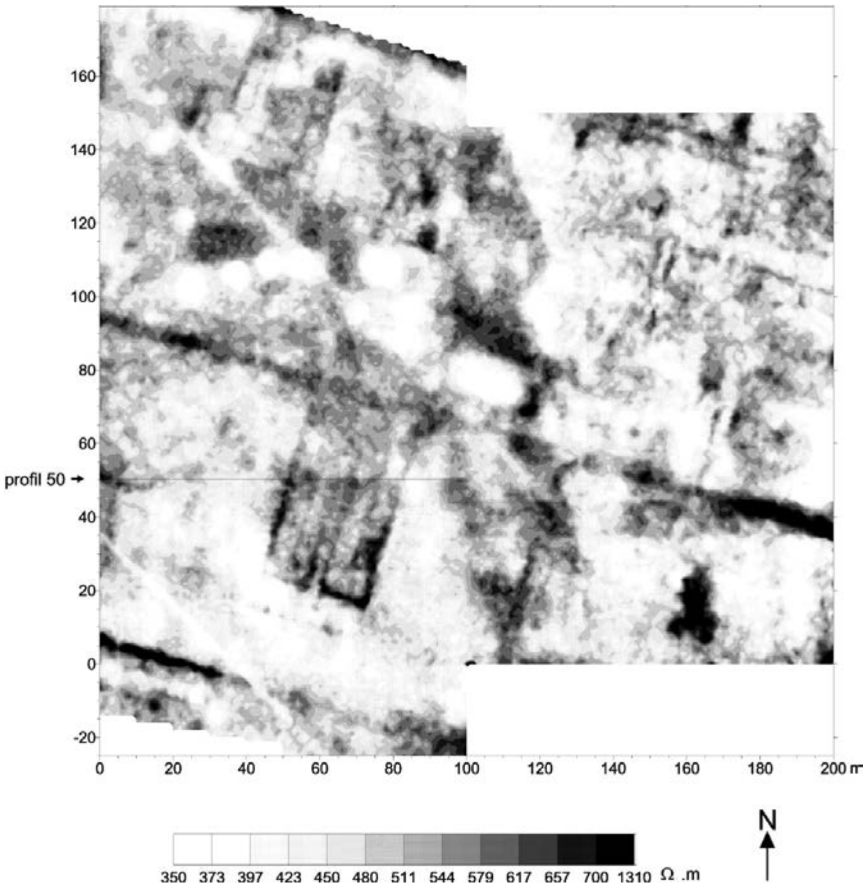


Figure 1.25: Resistivity survey using spiked wheel array. (*Insulae* IX, X, XII, XIII.) Courtesy M Debas and colleagues.

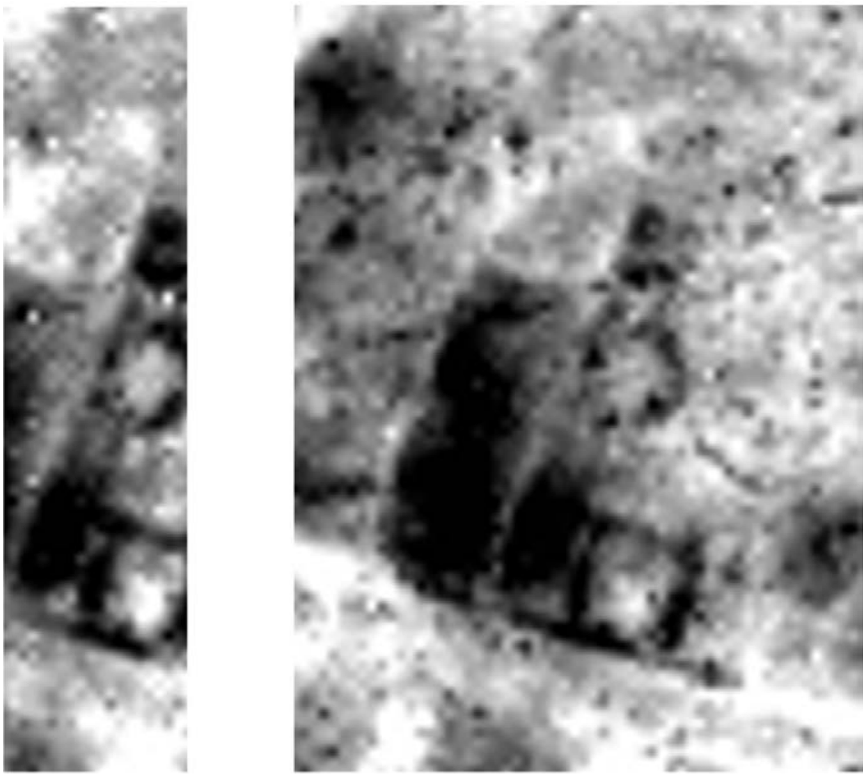


Figure 1.26: Survey and image of *insula* VI building by Paul Cheetham. On the left, is the 0.5m separation Twin-Probe, collected at 0.5m x 0.5m. On the right the 0.25 Multi Potential Electrode Twin-Probe, collected at 0.5m x 0.5m

the impact of the remote probes on the resistance reading. However, the significant part of the design is the light weight platform, which carries both the resistance meter and data logging computer, and is pulled across the ground using a harness (Figure 1.23). The results (Figure 1.25) again limited to the field south of the Baths, are highly revealing, are consistent with Walker's smaller survey and correspond well with the aerial information for the field. Another modified Twin-Probe arrangement was used at the site during SET97. Paul Cheetham showcased a 'multi-potential electrode' Twin-Probe in the area directly to the east of the baths complex (*Insula* VI) and covering an area of 60 x 60m. The modified arrangement, although fully to be evaluated, has shown some potential for reducing noise and sharpening some high resistance responses (Cheetham 2001; Gaffney and Linford 1999). The data from the two resistance data sets collected by Cheetham look reasonably similar (Figure 1.26), but of more interest is the variation shown with respect to the floor plan provided by the fluxgate survey at this point. Although the latter suggests a coherent building phase, the resistance data sets appear to indicate a variation in construction material.

Given the limited amount of area resistance survey at Wroxeter, it is worth reflecting on why this should be the case. It is apparent that both Roberts and Dabas have mapped geological as well as archaeological changes, but the variation in probe geometry demonstrated by Walker allows a subtlety in imaging that the magnetometer data cannot provide. While it is slower to collect resistance data due to the need to insert the probes into the earth, recent advances in collecting area resistance data via human- or vehicle-towed devices partly reduces that problem (Walker *et al.* 2005, Dabas 2009). While the question of speed can be addressed, there are still other issues regarding the interpretation of area resistance data that may be responsible for this lack of survey. For example, it is well known that seasonal moisture variation can have a dramatic affect on the resistance values measured at the surface. A monthly res-survey at the Stanwick Roman villa (David *et al.*, 2008, 27), illustrates the variability that can occur over an 18 month period. The results from that analysis illustrate the challenge that occurs in undertaking large-scale resistance survey; the variation in contrasts between features and background can be very large and this can be particularly problematic if the data collection is either slow or piecemeal. Both situations require significant processing to match data collection events, and there is no certainty that 'detectable' archaeology can be fully visualized even after processing. While it is evident that a complete area resistance survey of Wroxeter would be beneficial for research and management purposes, the question remains how would one go about this given the variability in contrasts? A research design for such an undertaking and based at this site would have to consider the following:

- Pilot Study to obtain maximum contrasts; this does not necessarily require new data collection. A number of 'time-lapse' surveys have been undertaken and it would be valuable to link rainfall to response and therefore use rainfall records local to Wroxeter as a gross predictor of greatest moisture contrast. In fact analysis of historical rainfall records linked to dated aerial photographs would also be extremely valuable as grass marks often show clearly after earth resistance contrasts have been lost or modulated beyond recognition.
- The question of which earth resistance array to use is important. As we have a 'blue-print' to work towards from the fluxgate survey the Wroxeter site is ideal for analysis of novel or modified arrays.
- Prioritizing areas within the city is clearly important as it is unlikely that the whole city can be surveyed in one go.

An interesting footnote to area resistance / resistivity mapping can be found in the MSc dissertation of Kösters (2001) who trialled the 'Ohmmapper' system over an area of 60 x 180m of *insulae* VII and XIX (Figure 1.27). Rather than inserting probes into the earth, capacitative measurements are collected by producing an alternating current in the subsurface via an alternating flow of charged particles introduced by electrodes insulated from the earth (Panissod *et al.* 1998). While such surveys have been shown to be valuable on 'difficult' terrain for traditional

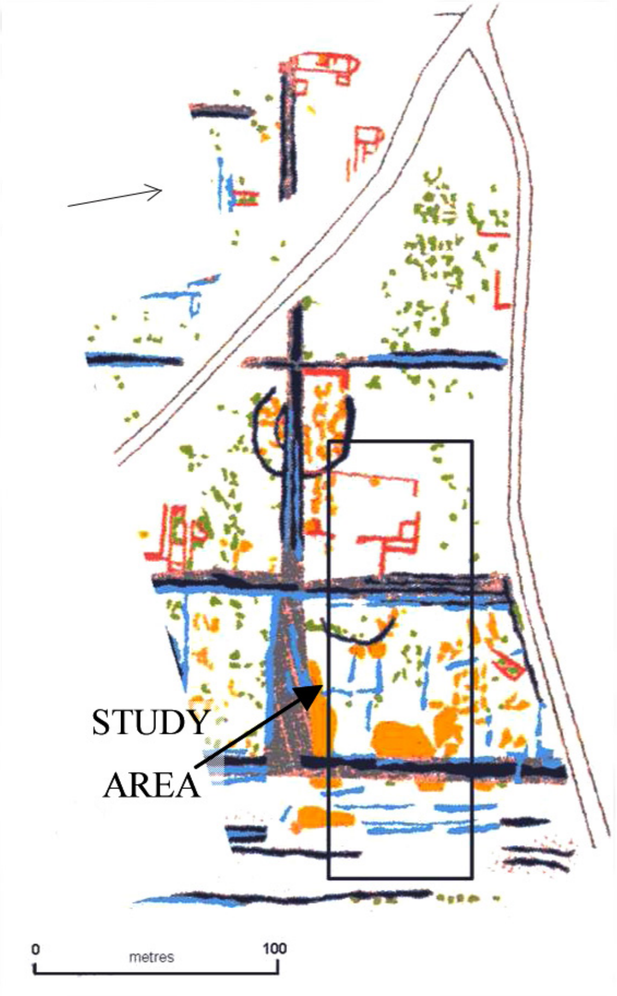
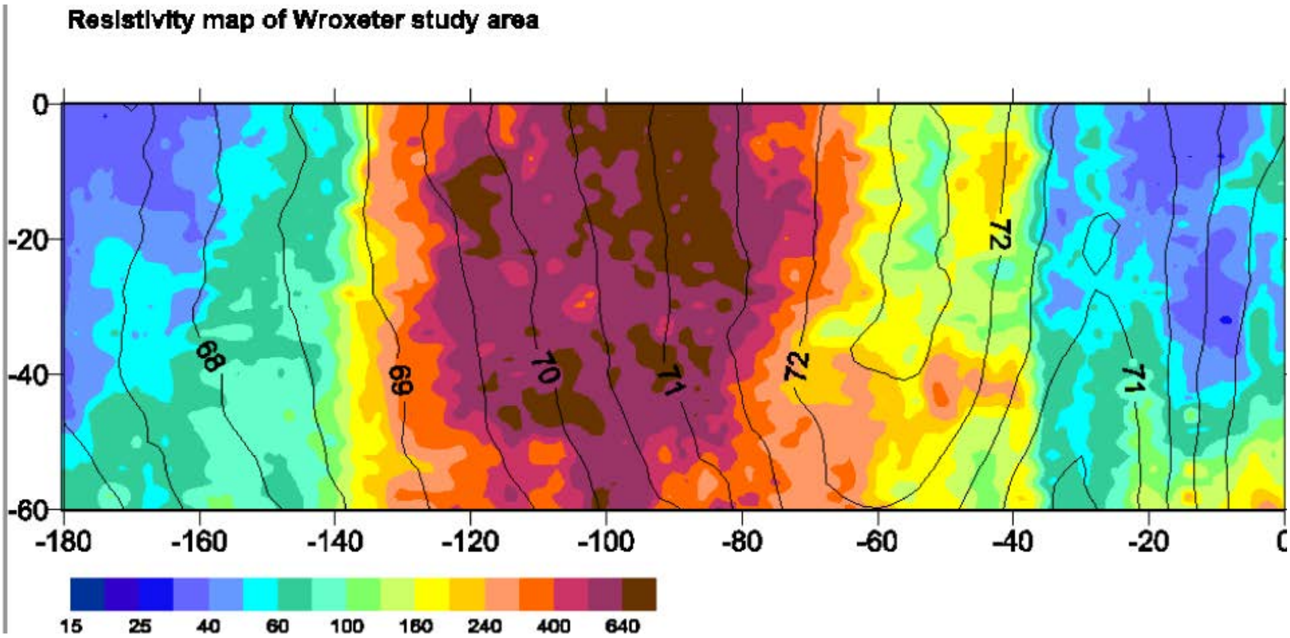


Figure 1.27: Koester's survey area in *insulae* VII and XIX. Note that north is to the right in this image.



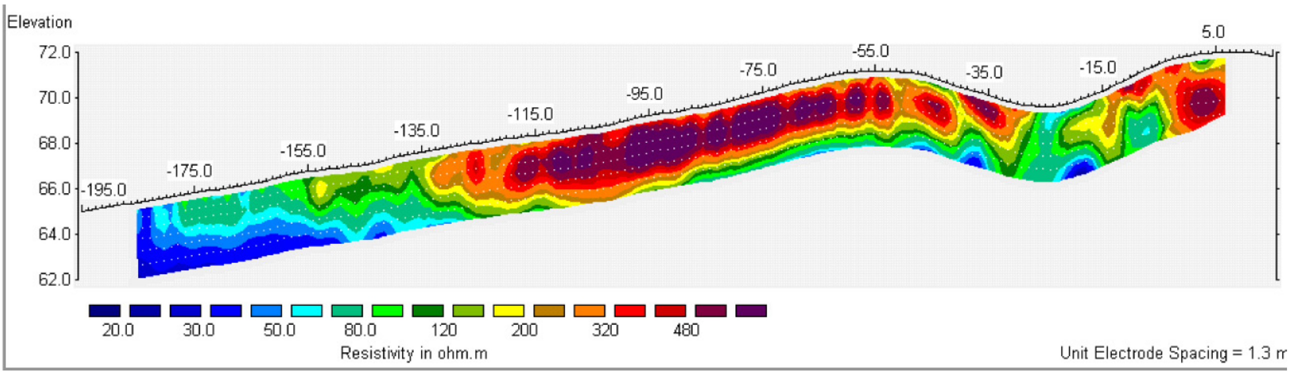


Figure 1.28 (top) Final map, with topographic information overlain. There is an interesting block of high resistance between the two roads. We suggest that both the topography and geology may have an influence here. The system is optimized for 1-2m depth, so it is likely that we can describe at least some of this variation as archaeological.

Figure 1.29 (below) A topographically corrected Electrical Image section taken from Koesters (2001). It is situated along the bottom edge of the study area. We suggest this supports a geological origin for the high resistivity anomaly in the central section.

electrical survey (dry or physically impenetrable surfaces), capacitive coupled arrays evidently have problems coupling on uneven ground. While it is likely that this technique will excel at the location of deeper archaeological or environmental targets, the imaging of the shallow zone is more inherently problematic (Linford 2006).

Kösters, however, argued that Wroxeter, far from being a good site for traditional resistance survey is actually ideal for capacitative systems. The logic behind this is that capacitative systems require highly resistive ground to function and that these conditions are the most problematic for the traditional systems. Kösters found that he achieved good reproducibility along each line using a dipole-dipole resistivity array, but the resulting area map (Figure 1.28) does not reflect the archaeological image that has been expected from the many magnetic surveys in this field (see Figure 1.21). It is likely that the Kösters map reflects the underlying geological variation rather than archaeological structures (Figure 1.29). There are good reasons for this; primarily there is a problem in coupling sufficient current into the ground when the lateral extent of the array becomes small. Evidently in this case the array was relatively large to counteract this problem and probably oversamples the underlying strata. Despite this, patterning is apparent and appears to relate to both geological changes and overlying archaeological detail. However, more survey would be required to comprehensively identify the true value of this technique beyond mapping the underlying geology.

Investigation using individual traverses / depth sections

A number of groups have collected resistance data at Wroxeter for manipulation into depth sections. This is undertaken by expanding a (four probe) electrical array around specific and regular locations, usually by means of a line of many probes spaced at equal distances. The data collection is facilitated by electronically switching between a pre-programmed selection of probe geometries. Depending on which array is used a specific depth can be assumed for each measurement and a 'pseudo-section' can be drawn. However, the resulting data rarely equate with the physical reality of the variations in the ground as the passage of the current via the inhomogeneous earth is excessively modified in the vicinity of an archaeological feature that contrasts significantly with the surrounding soil. This usually needs to be corrected prior to interpretation, normally by 'inverting' the data using a two-dimensional forward model or a tomographic routine. The resulting image is similar to a drawn section of an excavation. Although a mesh of traverses collected on a grid can be created to analyze a volume of earth (see Berge and Drahor 2011), at Wroxeter investigations have largely used single traverses. The origins of this form of investigation lie outside of archaeological geophysics and the relatively large separation between probes that has been conventionally used has resulted in this technique being used to investigate the deeper archaeology, or the background geology, at the site (see Bates *et al.* (2007) for the wider context).

The site of Wroxeter has been used by at least three groups (GSB Prospection, University of Birmingham and University of Keele) to investigate aspects of the depth of deposits using electrical methods. They have used both the ABEM Terrameter and the Geopulse systems, largely with electrodes spaced at either 0.5 or 1.0m and switching between successive Wenner or Dipole-Dipole readings. In part the results reflect similar problems (with respect to seasonal contrast) associated with the area data, and for these techniques to make a real archaeological contribution the research agenda at Wroxeter must be carefully drawn up. So far pseudo-sections or inverted sections have been undertaken over obvious or structural elements. While that is adequate for teaching purposes, the opportunity for identifying new or clarifying 'problematic' archaeology is limited. It is suggested that it would be beneficial if this form of investigation is targeted toward areas of the town where deep deposits may exist or investigate areas of complexity using close spaced transects (Figure 1.29). Undoubtedly investigation of depth using these techniques could be usefully re-investigated in light of recent technological changes.

Electromagnetic

Electromagnetic (EM) instruments have long been popular in the search for deep natural changes and have found a niche in the detection of landscape features that have archaeological relevance, such as palaeochannels or gravel islands buried beneath alluvium (Bates *et al.*, 2007). The devices that are commonly available utilize a transmitter to generate the investigative signal and a receiver that is either within the same housing, or separated at a fixed distance. The receiver may be programmed to analyze amplitude, phase lag and time delay with respect to the primary (investigative) signal. The most commonly used EM instruments for archaeological prospecting (e.g. Geonics EM38) using separate transmitters / receivers at a fixed distance are sometimes called 'Slingram' devices. In this case a continuous wave is transmitted and is used as a reference. Along with the frequency of the transmitted signal (usually tens of kHz), the distance between the coils and their orientation are very important as they will determine potential depth of reconnaissance. Additionally, under certain circumstances (called 'low induction numbers') these devices operate in such a way that both conductivity (the reciprocal of resistivity) and magnetic susceptibility can be evaluated. Given that earth resistance and the variation in magnetic susceptibility (see magnetometry above) are the two traditional measures used to predict buried archaeological features then this class of instrument could be valuable for prospecting at Wroxeter. This is particularly true for the measurement of conductivity as the devices are carried above or pulled along the ground, thereby reducing the problems of ground contact in traditional resistance surveys.

Two Slingram devices have been used at Wroxeter; Geonics EM38 (Figure 1.30) and EM31. Essentially, the EM31 is used for deep investigation (in the order of 6 m), while the EM38 has a similar depth penetration to the standard Twin-Probe resistance setup (0.5 – 1.0 m, see Cole *et al*. 1995). While the potential for this class of

Figure 1.30 An EM38 in use at Wroxeter. (Photo R. White)

instruments is great they have been generally underused at Wroxeter. All of the EM work at Wroxeter has been small-scale and linked to either teaching or demonstrating; there has been little archaeological output as the data collection effectively has not been linked into any overall research objectives for the site. There is increasing evidence that recent developments in EM survey have contributed to the possibility of undertaking fast, data-dense and large-scale survey at sites the size of Wroxeter (Simpson *et al.*, 2009).

Metal detectors are also EM devices, although they are rarely regarded as geophysical instruments due to the fact that they are usually used to search for artefacts rather than feature detection. Of the devices that are used for archaeological purposes many are Pulsed Induction Meters (PIM). PIM work by pulsing short duration electrical currents in the transmitter, which in turn create eddy currents in conductive bodies within the locality of the coil. The receiver monitors the decay of signal produced by the conductive body. These devices are, as their name suggests, ideal for identifying metal and they are rarely used on scheduled sites for fear of attracting attention to the possibility of buried 'treasure'. However, at Wroxeter a metal detector (a Goldscan II) has been used on at least one occasion in the area around the find spot of an item of Roman silver (David and Payne 1990). Given the protected status of Wroxeter it is difficult to see how traditional metal detectors can be used within the site in any significant way.

Ground Penetrating Radar (GPR)

GPR is a subset of EM devices, but the energy that is transmitted for archaeological purposes is usually in the order of 200 – 900 MHz, as opposed to the lower frequencies used by Slingram devices. For most GPR systems a transmitter emits energy around a central frequency and a receiver is used to collect the returned signal which is recorded in terms of amplitude and two-way time. Measured reflections are a result of changes in conductivity or dielectric permittivity resulting at the boundaries between materials. The latter is the ability of a material to store a charge from an applied EM field and then transmit that energy (Conyers 2004, 45).

As this technique can provide potentially accurate information at accurately determined depths along a traverse there is clearly a role for GPR in the investigation of a multi-period site such as Wroxeter. However, there are many factors to consider before maps at definitive depths can be made. The depth and resolution of a system is dependent upon the centre frequency of the antennas attached to the system, while local conditions can dictate how efficiently the energy can pass into the ground. GPR tends to work best in soils that are relatively dry and contain sharp boundaries that the energy will reflect from. If the opposite conditions are in place then it is found that the signal is attenuated due to the energy of the radar wave being converted into heat and the lack of a distinct boundary means that signals fall below detectable levels.

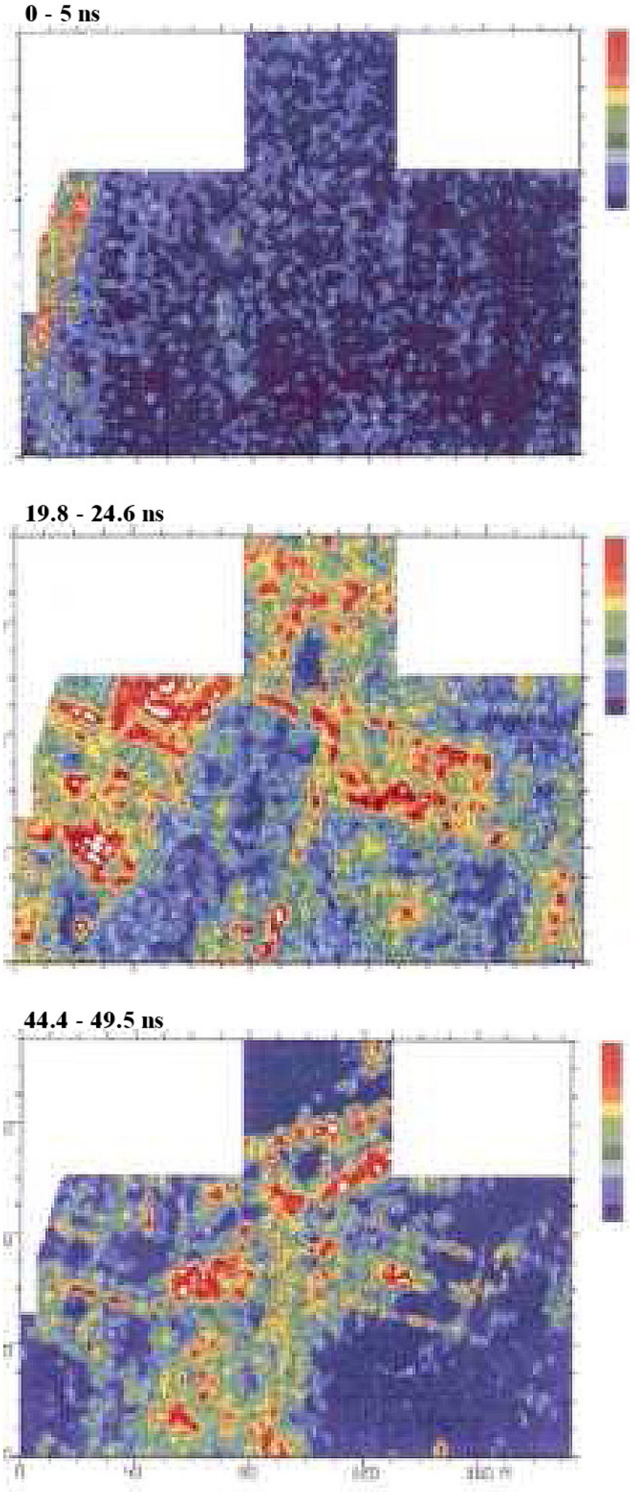


Figure 1.31: Time-sliced GPR data collected in 1995 over *insula* IX. Courtesy Nara Research Institute

The majority of GPR data collected at Wroxeter has used frequencies in the range 200-500 MHz, which are commonly in use in archaeological investigations. All data have been captured along traverses ('radargrams'), although some of the surveys have collected multiple parallel traverses allowing the resulting data cube to be sliced horizontally to produce maps at pseudo-depths; these are normally termed depth maps or timeslices. To achieve depth maps the velocity of the energy through the ground must be accurately known, and this is not an exact science. For a particular position on the ground the velocity may be estimated by survey over a feature at a known depth, Common Mid Point (CMP) determination in the field or analysis of hyperbola in the collected data. However, the calculated value may not hold true for the velocity elsewhere in the survey area. As a result conversion to depth is only approximate, and that is particularly true when there is a high degree of variation in soil moisture content (Conyers and Lucius 1998). As a last resort standard tables exist illustrating the range of velocities known for certain materials and they can be used as a rough estimate for depth determination.

Figure 1.32: Dean Goodman (l) and Yasushi Nishimura (r) undertaking a GPR survey at Wroxeter, 1998. (Photo R. White)

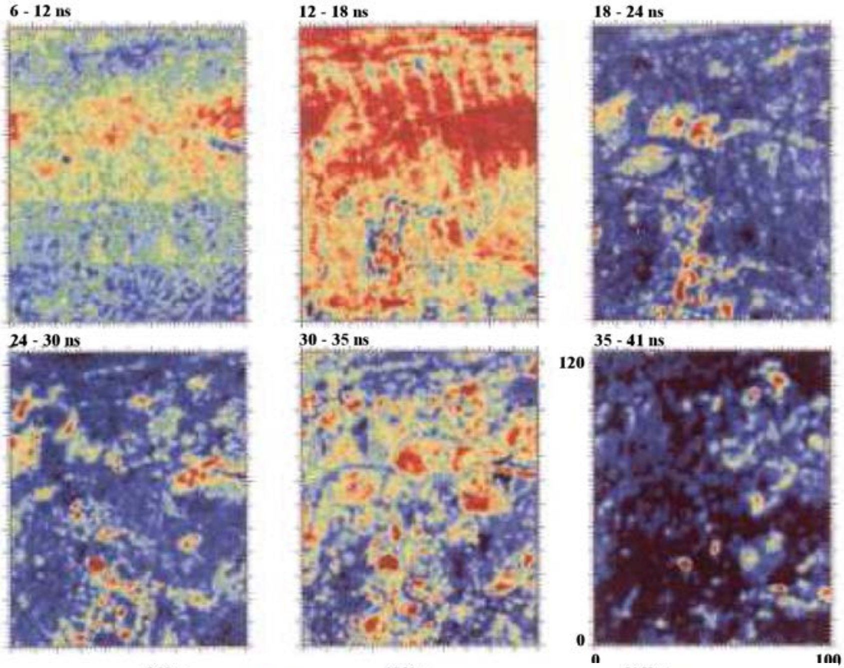


Figure 1.33: Initial GPR data collected in 1998 over the substantial building in *insula* XV/ XXIX. While not as good as the data collected with the closer resolution (see Figure 1.34), note that it has located ridge-and-furrow (middle image top row). Courtesy Nara Research Institute.

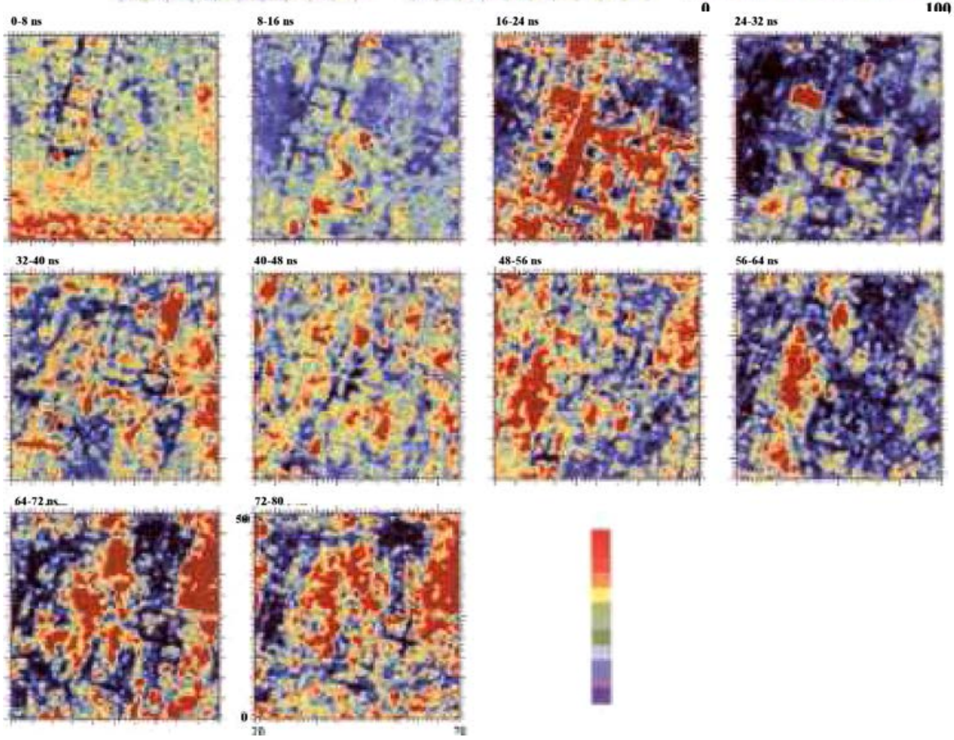


Figure 1.34: Part of the 1998 survey resurveyed at 0.5m traverse intervals and showing major benefit in visualization and interpretation. Courtesy Nara Research Institute.

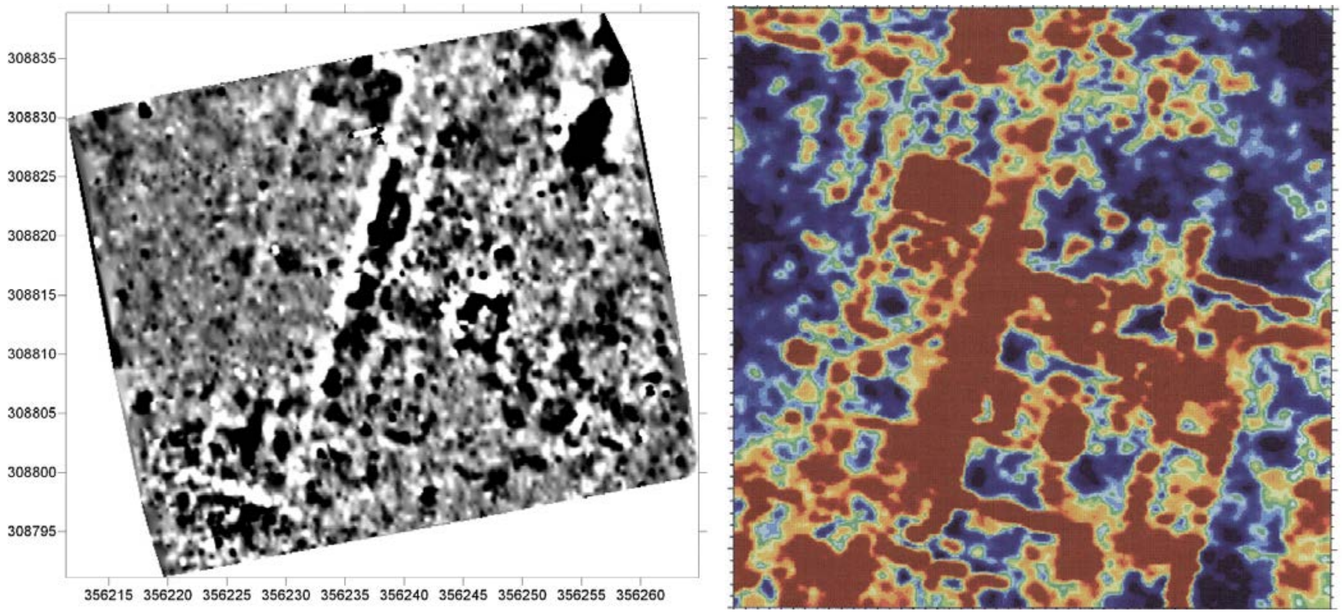


Figure 1.35: A comparison between a 2009 magnetic survey using the Foerster system (l) and the 1998 GPR survey (at 16-24ns depth) (r). Courtesy Eamonn Baldwin, VISTA, University of Birmingham

In 1995 Yasushi Nishimura and Dean Goodman (2000) undertook at Wroxeter what was then the largest GPR survey in Britain for archaeological purposes using a GSSI SIR-2 system and a 300MHz antenna. The survey area, centred on the Kenyon house, was about 2ha in size and the data was collected in 4 days using a traverse separation of 1m (Figure 1.31). While it was clear that archaeologically important information was contained within this data, there was evidence of excessive noise due to rain penetrating the antenna housing. As a result the authors collected data at a second survey area on *insulae* XV / XXIX in 1998 using another 300 MHz antenna (Figure 1.32). Again the authors managed to survey in excess of 1ha, but although the data was significantly less noisy than the 1995 survey, the so-called 'timeslice' images were not particularly sharp (Figure 1.33). Part of the area was re-surveyed with an inter-traverse distance of 0.5m and the resulting image provided very clear results (Figure 1.34). The significance of this re-survey is that since that time the higher spatial density of 0.5m between traverses collected with antennas of 200-300MHz has become the standard for timeslice preparation. In this work a velocity of 0.06m ns^{-1} was assumed for the passage of the energy through the soil and therefore a depth of penetration of about 4.5 m was achieved. While this is only an estimate, it is likely that the actual depth was extremely variable across the survey areas and was probably much less than 4.5m. It is interesting that the authors note that the majority of the archaeology appears at a relatively shallow assumed depth in the GPR data.

Apart from the original Nishimura and Goodman paper there is little other coherent data to draw upon. The majority of the GPR survey work since then has been for student teaching or small scale tests. It is evident that Wroxeter could be extremely invaluable for large scale GPR survey; tests on rapidity, multi-frequency and modelling for interpretational purposes could easily be incorporated into the archaeological investigation of the town. The interplay between the GPR and the magnetic data sets from this site has really not been fully explored. A recent magnetic resurvey of the Nishimura and Goodman 1998 survey using the Foerster cart system described above illustrates the complementary nature of the techniques (Figure 1.19).

Seismic

Figure 1.36: Carrying out a seismic survey at Wroxeter. (Photo R. White)

Although the seismic method is one of the more common methods used in large scale geophysical investigations, it is comparatively rare for very shallow exploration (but see recent developments in Metwaly *et al.* 2005). During a seismic survey a 'wave' of acoustic energy is introduced into the ground. The source of the energy is usually a sledgehammer struck against a metal plate, although other more sophisticated ways of producing the required energy can be used e.g. explosives. When the energy meets an interface between different materials it is either refracted or reflected and these phenomena are the basis for seismic refraction or seismic reflection. It is the former that is believed to be of most use in shallow investigations, and is certainly the method used on a number of occasions at Wroxeter. The time taken for the wave to return to the surface is recorded and can be converted to depth and analyzed in a manner similar to GPR. Seismic survey is generally employed to reveal layering within the subsurface and considerable challenges occur when complex geometries are investigated. The wavelength is also relatively large by comparison to small-scale archaeological features, and as a result of these two limitations most of the published archaeological examples involve the detection of large scale, landscape features rather than intra-site variation (e.g. Ovenden 1994).

The kit for a typical refraction survey includes an energy source, detectors (geophones) equally spaced along a long line and cable to link the geophones to a computer. In all of the applications of seismic survey within Wroxeter the data were collected along single lines with the intention of demonstrating the suitability of the method. The majority of the data has been collected during student training and the analysis has been very specific.

1.6 CONCLUSION

The results of geophysical survey at Wroxeter have proven to be exceptional in their capacity both to support and to enhance information acquired by antiquarian research, systematic excavation and extensive aerial photographic survey. For many the geophysical base map of the town remains the magnetic image derived from the 1990s, but this volume clearly reveals the additional dimensions from the other data sources.

The site's complimentary role as an open-air laboratory, presumed in the surveys undertaken as part of the Wroxeter Hinterland Project (Gaffney and White 2007) is likely to be maintained but in carrying out this work archaeological scientists have demonstrated their capacity to contribute to national research agendas, not simply in terms of novel technology, but also in respect of urban development and characterization, studies of demography and carrying capacity.

This chapter has essentially provided an outline of previous research but it is appropriate that some comment should be made on future research agendas. Primary development of remote-sensing technologies will always be central to the improvement of our knowledge of the urban area of Wroxeter yet the full potential of the data may only be achieved through studies that incorporate multi-method surveys within a more sophisticated interpretative scheme.

It is probable that the inclusion of complementary technologies, such as the systematic study of soil chemistry and, more likely, projects that facilitate data fusion in a manner that was not feasible given the computational facilities available to past researchers, and will add great value to the present data sets (Watters 2006). Remote sensing has transformed knowledge of Roman Wroxeter but there is still more to do.