From Artefacts to Anomalies: Papers inspired by the contribution of Arnold Aspinall

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No further territorial demands: on the importance of scale and visualisation within archaeological remote sensing

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"Measure not by the scale of perfection the meagre product of reality."
Friedrich von Schiller

During its early period of development geophysical survey in archaeology was essentially carried out to identify suitable areas for excavation within sites that were already known. The work was also characterised by the relatively small scale of projects carried out and the relatively low value of such surveys, in larger interpretational terms, to archaeologists. There were of, course, many fundamental reasons for such a situation and not least amongst these was the low expectation of archaeologists themselves for the technologies beyond the role of prospection. It is, of course, true that the instrumentation available was not actually conducive to large area surveys in terms of its capacity to record data or, perhaps, the design of the equipment itself.

The first surveys involved unwieldy apparatus culled directly from what we now call Earth Science; this included basic measurement devices such as the Megger Earth Tester **(Figure 1)** and the classic resistivity arrays such as the Wenner. Processing power to manipulate the data was also minimal.

Figure 1. A Megger Earth Tester. There is a wind up handle on the side for taking measurements.

Indeed in the early days, data capture and processing were frequently a manual

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operation involving hand-written grids of readings **(Figure 2)** from early resistance meters or gradiometers and the contouring of data by pen or coloured pencil! This in itself was no bad thing; Arnold Aspinall often told all would-be-surveyors that a good geophysicist knew what was in their data by the time they left the field. This was bolstered by Arnold's belief that if it didn't exist in the raw data it didn't exist full stop. Of course, few practitioners had access to serious computing or processors that could handle significant amounts of data. Notable exceptions include work undertaken by Irwin Scollar and Richard Linnington and reported in the now defunct journal *Prospezione Archeologiche*. Output was, of necessity, limited under such conditions and this was reflected in the scale of the projects undertaken and their relative simplicity. For instance, few multi-technique surveys were carried out essentially because of the complexity of integrating a plethora of disparate data sources. Where such work was attempted results were frequently a series of individual interpretations rather than an integrated exercise (Gaffney and Gaffney 2000). The classic example of this is the set of surveys, almost experiments, which was reported in 1980 by Fisher. However, the increasing maturity of the discipline can be seen in the occasional series of 'Geophysical Reports' edited by Arnold Aspinall and Jim Pocock. Revisiting these reports it is apparent as scientists the interpretations were always linked to statistical validation. This was destined not to last as the subtlety of the record became apparent. In fact by the mid 1980s Arnold was heard to say 'why do you need to prove that statistically when it is bloody obvious'!

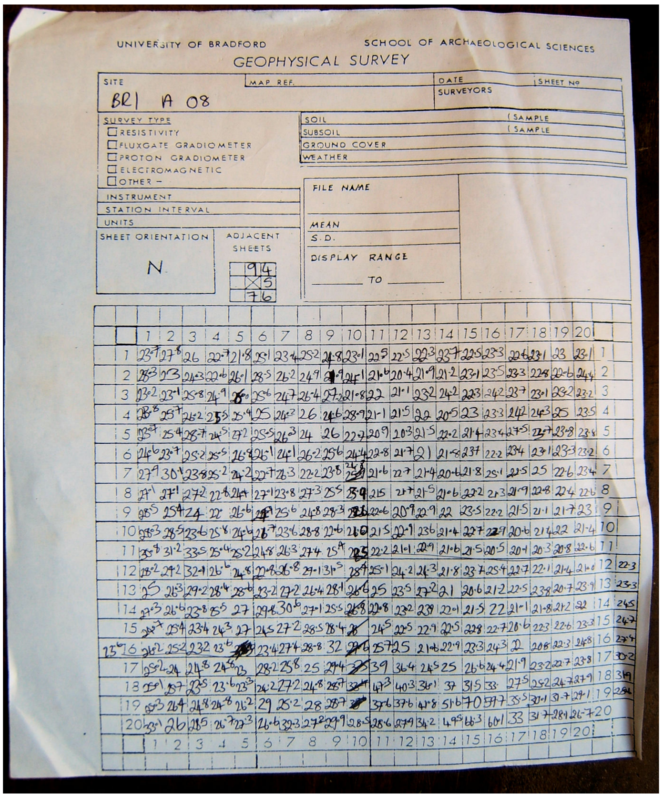


Figure 2. Hand logged data. Only half the details filled in (as ever), but with corrections down side of sheet!

Having said this, it should at least be acknowledged that the majority of field archaeologists during this early period were perfectly happy with the output of the small number of academic or state employed geophysicists supporting the discipline at that time. The reasons for this situation are equally varied but fundamentally the limited capacity of the early geophysical surveying pretty much reflected the physical scale at which most archaeologists worked. If geophysical surveys were constrained in scale for technical reasons, then so too were most field archaeologists. With the honourable exception of the work of pioneers in aerial photography, for example O.G.S. Crawford, and a limited number of other practitioners few archaeologists truly attempted detailed investigation beyond the confines of traditional settlements or archaeological sites with easily defined boundaries or well understood functions (Bowden 1999). This situation largely reflected the theoretical aspirations of the day. Essentially, this required the location of features or structures that might be dated or interpreted in a strict functional or morphological sense. The interpretation of geophysical techniques became dominated by this empirical mode of analysis.

This situation has changed considerably in respect of archaeology as an intellectual discipline and archaeological remote sensing as a technical pursuit. The roots of this diversification lies within the 'new archaeology' of the '60s and '70s, which additionally can be identified as a pivotal period where archaeometry and archaeological science began to drift apart (Gaffney and Gater 2003).

It must be acknowledged that there is now a multiplicity of technologies that may be used routinely on any archaeological site beside the traditional "workhorses" of geophysics: resistance and magnetometry. The advances in Ground Penetrating Radar (GPR), in particular, have been such that the technology has become a relatively routine archaeological application in some parts of the world. This technique regularly provides the elusive third dimension that had been beyond the capabilities of the methods used previously.

During the last decade or so the use of GPR in archaeological work can be regarded as surgical, with high-density surveys used to identify features within sites. However, the general use of highly accurate positional devices has brought ground-based techniques to the foreground of *prospecting* rather than *mapping* that occurs within most site-based exercises. Low-grade positional devices have been used for a number of years with electromagnetic devices, and their value for mapping large-scale changes relating to underlying former land surfaces and palaeochannels, now coming to fruition. They are also valuable for defining spreads of material associated with, for example, wartime aircraft crash sites (**see Figure 3**).

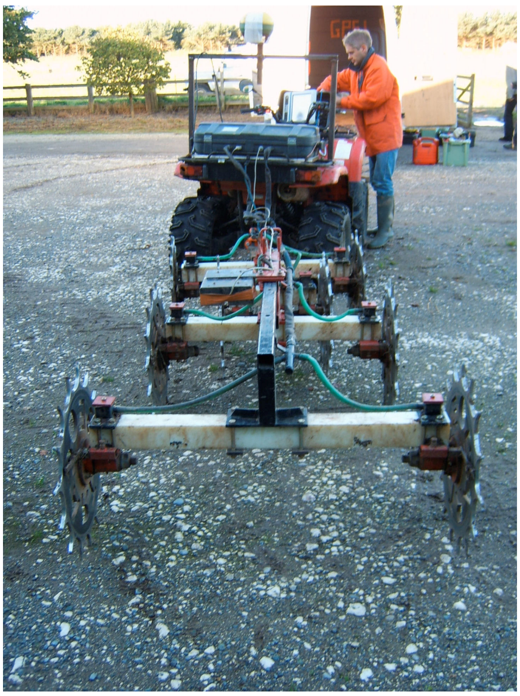
Figure 3. Ian Wilkins of GSB Prospection Ltd using an EM-61 with dGPS. Photograph courtesy of GSB.

The value in these systems is obvious; for example, there is little requirement for accurate pre-survey maps and a reduction in data collection time. A result is that some instrument manufacturers have produced fully integrated high precision GPS driven systems for magnetometry, resistivity and GPR. In the case of magnetic survey some of the systems are hand pushed on wheels and incorporate multiple sensors. The system produced by Foerster, which was originally developed for military purposes, is based around factory set fluxgates that require no field set up and are placed in a large sensor array **(Figure 4)**.

Figure 4. The Foerster FEREX system in operation at the University of Sienna Summer School at Grossetto, 2006. Photograph courtesy of the organisers of the school.

However, the hottest new magnetic device uses SQUID (Superconducting Quantum Interference Device) technology, which requires the sensors to be maintained at a temperature of *c.* 4 Kelvin. The system can be configured as a true gradiometer and, once superconductivity is achieved, the device can be pulled at great speeds behind a car (**Figure 5).**

Figure 5. Squid system developed by Schultze and colleagues ate the Institute for Physical High Technology, Jena (Germany).



In addition to data collection at great speed the SQUID technology allows very accurate measurements, easily outperforming other magnetic devices (Schultze et al 2005). The latest incarnation of the French mechanised resistivity system also has its roots in a non-archaeological application (viniculture) (**Figure 6**). Again, this is directed by real time GPS and can measure three depths of resistivity simultaneously (Dabas and Favard, 2004).

Figure 6. Rear view of the ARP resistivity system developed by Dabas and colleagues (Terra Nova).

Of course we have previously seen GPS added to GPR systems (Leckebusch 2005), and to multi-technique platforms such as the GEEP (Fuller et al 2006) and the Geoscan MSP40 (Walker and Linford 2006); see **Figures 7 and 8**). However, it is evident to see that the integration of GPS onto wheeled or sledge systems that are capable of being pushed or pulled at high speeds across survey areas that require no formal grid will begin to challenge the traditional use of these technologies. Aside from enabling greater quantities of digital data to be collected such developments are capable of empowering archaeologists in their exploration of buried or unseen landscapes and therefore of integrating ground-based remote sensing with the larger interpretative agendas that are at the heart of the discipline.

Figure 7. GEEP Multi-Sensor Platform

Figure 8. Roger Walker pulling the MSP40. From Walker and Linford 2006.

Whilst acknowledging the exciting innovations occurring within the domain of "traditional" geophysics, it is also important to note that the definition of what is considered under the banner of archaeological remote sensing might also have changed over this period. Sensors that provide a variety of metrics for archaeological purposes now include ground, air and satellite platforms. Although available for some time the primary driving force to include these technologies directly within the archaeological repertoire has been the increasing resolution of such sensors, a process mirrored by some traditional techniques as well. Thirty years ago the ability to map the Pyramids from space may have been an achievement in its own right but, with the exception of larger environmental studies, research at this resolution was unlikely to transform archaeological understanding (Quann and Bevan 1977). However, emerging sensors, particularly those in air-based platforms, have increased utility as a consequence of their impressive resolution and are now frequently used alongside traditional aerial photography for the purposes of archaeological prospection (http://arsf.nerc.ac.uk/instruments/).

Whilst some purists might demand a significant distinction between ground and non-ground based remote sensing, there is an important point that can be made here in respect of terrain or surface data. This is an increasingly important archaeological metric that has traditionally been the preserve of the draftsman rather than the natural scientist within archaeological research. Output of these data has generally been qualitative, in terms of interpretative mapping, or semi quantitative, at best, in respect of contoured data. However, the increased use of numeric terrain data or derivatives as continuous surfaces within archaeology, usually within GISs, and the development of laser high definition survey technologies over the last decade suggest that these technologies are likely to occupy a strategic, hybrid position in respect of remote sensing. These technologies, which occur as ground (HDS) or air-based (ALS or LiDAR) applications (Challis 2006, English Heritage 2006a), may derive near continuous measurements of the surface of the ground or archaeological features. The resolution of such data can approximate that of traditional ground-based remote sensing, and therefore provide important information on individual features i.e. below the scale of the site.

However, the larger significance of the technology may lie in the intermediate position that 3D terrain data hold between the site and extensive remote sensing survey, aerial photographic or air or satellite sensor data. This is important because archaeology has witnessed a major theoretical shift to incorporate the landscape as part of its interpretative narrative (Tilley 1994, Johnson 2006, xiii-xxiii). Space and the physical structures of the landscape are no longer seen as the passive natural background to human activity but rather as critical social variables that are formative to historical action. Consequently, LiDAR may provide a previously missing numeric link between the data provided by a range of remote sensing technologies and the physical structure of the terrain itself. The significance of this remains to be seen but the increasingly pervasive use of terrain modelling within archaeological research (Chapman 2006; Lake and Connolly 2006), and the significance of landscape structure within many aspects of archaeological theory, suggest that enhanced surface data may prove to have a major impact on how archaeologists relate to their data across the entire spectrum of human behaviour.

It should, of course, be stressed that LiDAR and laser High Definition Survey do provide other remote sensing attributes that may afford a more substantive, perhaps traditional, multispectral function. The potential of LiDAR laser intensity data as a guide to other physical qualities of the landscape is currently under investigation in respect of the mapping of palaeochannels (Challis 2006, whilst a similar potential has been noted for the use of intensity data acquired by ground-based HDS scanners (**Figure 9** and English Heritage 2006b, figure 31)

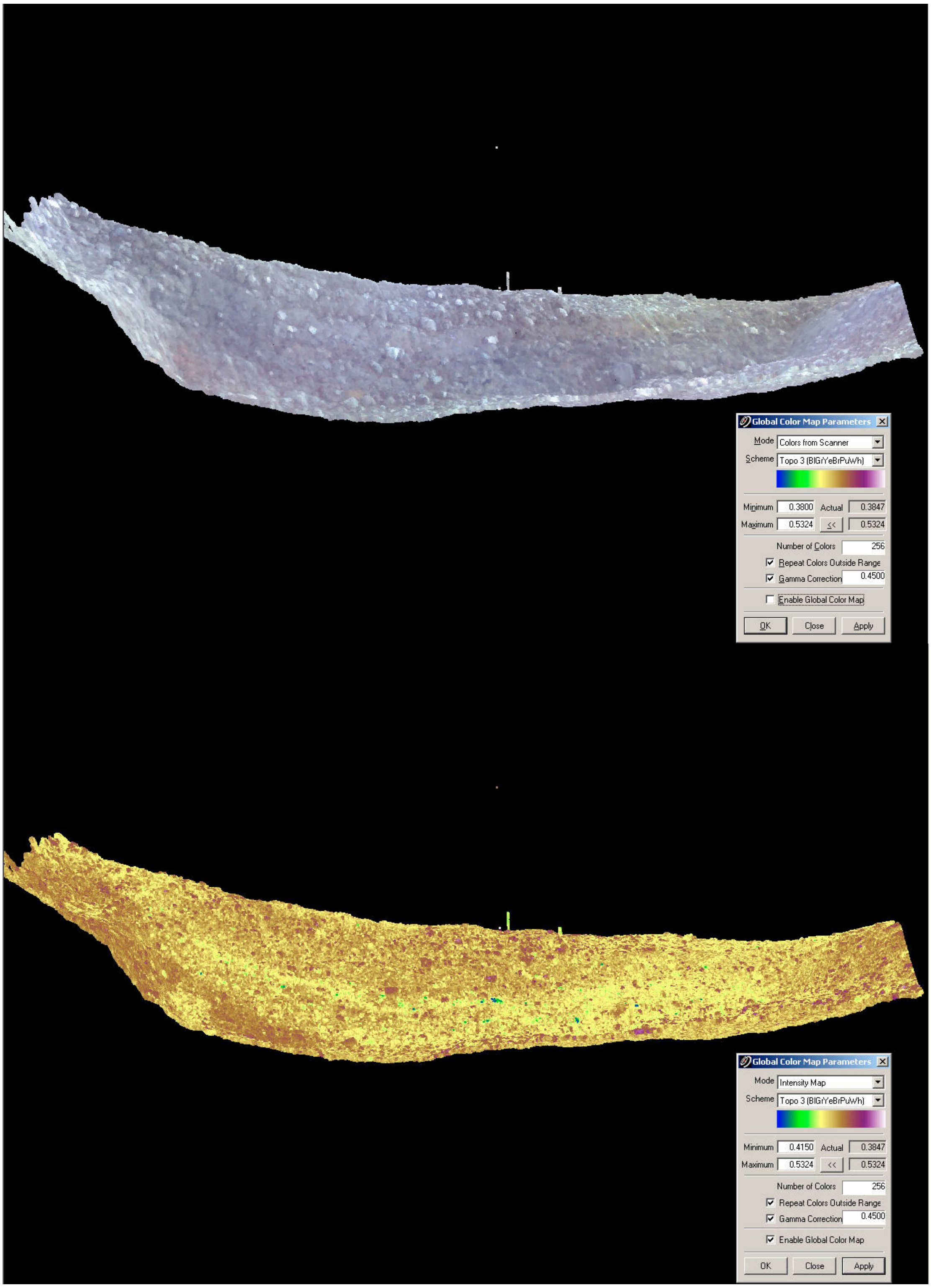


Figure 9 Images of a cess pit profile scanned using a Leica Cyrax laser scanner. The top image shows the 3D data overlain with the photographic image of the pit, the bottom shows laser intensity data and illustrates the different stratigraphic information potentially provided by laser intensity mapping (source Professor Mike Fulford).

Together with the expansion of available methods there has been a rapid development of more powerful instrumentation. Workstations have developed exponentially in terms of processor power whilst field instruments have acquired an enhanced capacity for data logging and processing in their own right. Restrictions on the physical data storage capacity can, to some extent, be equated with a potential increase in the physical scale of application, either in data resolution or spatial extent, and this has its own significance given the observations on the expanding theoretical aspirations of the archaeological community noted above. In some ways, the most exciting area of development has been that associated with processing and visualisation software. From the days when plots were little more than a square inch of graphical output from an Epson HX20, physically pasted together for examination, today's specialist software provides a host of algorithms for processing, edge matching, georeferencing and display of data (**Figure 10**).

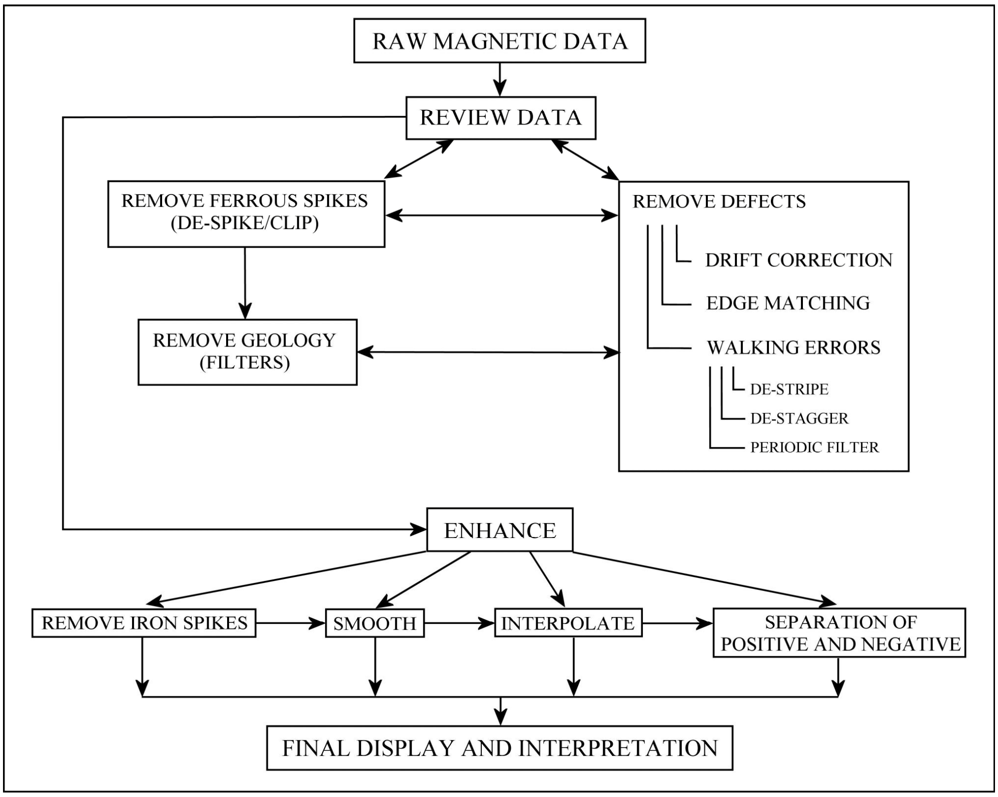


Figure 10. Typical flow chart for processing magnetometer data. From Gaffney and Gater 2003.

However, impressive as this may be several factors deserve specific comment. It has been apparent for some time that software development has become a more generic activity. In part this is driven by the primary spatial (digital) nature of the data and this is not specific to archaeology, geophysics or any other aspect of remote sensing. Visualisation of spatial data, in particular, is a general activity although there is a clear trend towards the addition of modules with some capacity for processing remote sensing data to softwares that may have more sophisticated visualisation capabilities, or the facility to integrate remote sensed data with other spatial information. Obviously GISs come to the fore at this point, and it is no coincidence that these softwares have rapidly developed a range of image processing modules which expand their capacity to analyse rather than simply manipulate and display remote sensed data. It is true, however, that such analytical features are aimed at pre-processed geophysical data or continuous data from satellite or other sensors. Important features for other technologies, for example edge matching, are likely to be absent from these packages and will remain an important niche in specialist processing software.

However, the general development of visualisation software suggests that the trend towards the integration of analytical / processing algorithms may be reinforced (Gaffney forthcoming). The requirement of surface rendering or solid modelling applications for 3D data, notably GPR, electrical tomography or seismics, is a case in point. The underlying visualisation libraries for some specialist softwares at least frequently derive from specialist packages with origins in medical or Earth Science applications. For example, in the case of seismic softwares, Mercury's Amira visualisation libraries underpin the Kingdom processing suite whilst AVS is associated with TIGRESS.

Perhaps nothing demonstrates this point more dramatically than the Birmingham project on the Palaeolandscapes of the Southern North Sea (**Figure 11,** Fitch et al 2005). This project seeks to explore the vast areas of populated landscape inundated during the last great period of global warming and now represented by the area of the Southern North Sea. This great plain was probably the heartland of the Mesolithic populations of North Western Europe but was lost between the end of the last glacial maximum and c. 6,000 BC. Eustatic movement and sediment deposition followed inundation such that today we can barely trace the outline of this landscape.

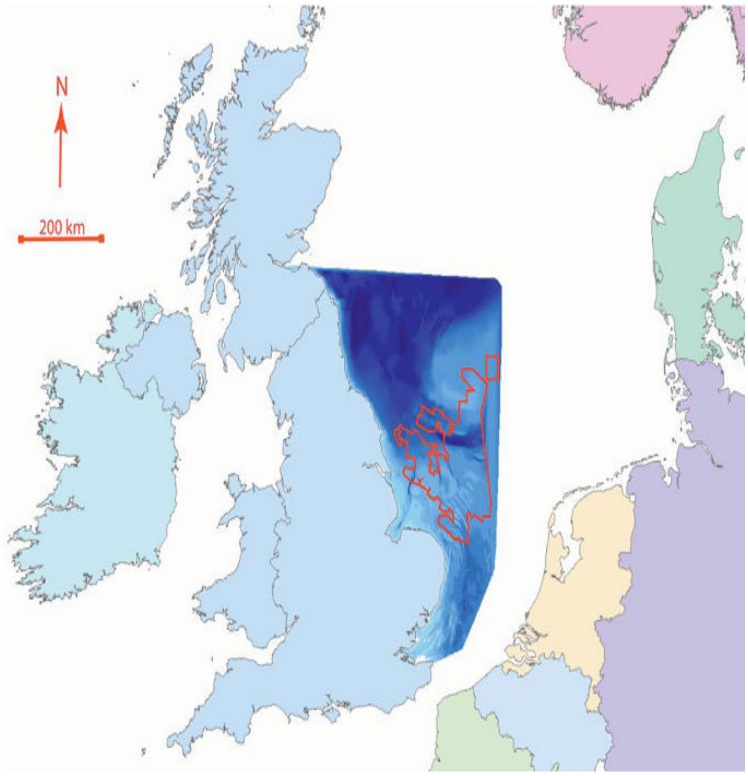


Figure 11 The North Sea Palaeolandscapes Project study Area (outlined in red)

The research team in Birmingham, funded by the Aggregates Levy Sustainability Fund, is currently mapping more than 22,000 km^2 an of this landscape using 3 Dimensional seismic data collected for the purposes of oil and gas exploration and provided by PGS. This is an archaeo-geophysical survey the size of the Wales whose analysis could have never previously been attempted using traditional remote sensing technologies. The visualisation of these territories, which include the rivers, hills and valleys that have been lost for more than eight millennia, is such that, in respect of the scale of analysis within this project, archaeological remote sensing is now moving from being a landscape technology to one that operates at a national scale and therefore feeds into archaeological agendas at every level. In terms of processing, new problems are being encountered with respect of the size of the datasets (potentially up to one Tbyte in the case of the Southern North Sea base data set), and the requirement to model such data in terms of volumes or solid or voxel models rather than as 2D maps or even 2.5D surfaces (**Figure 12**).

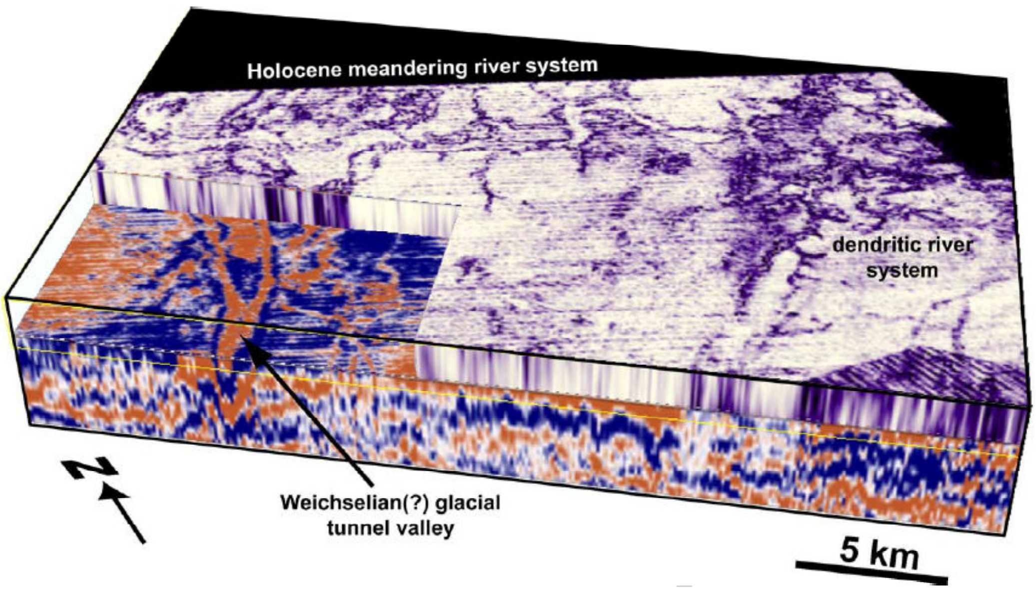


Figure 12. Seismic amplitude volume overlain by a seismic coherence volume. The figure demonstrates that the probable Weichselian tunnel valley pre-dates the meandering river system which is consequently of Holocene age (after Fitch et al. 2005).
http://www.iaa.bham.ac.uk/research/fieldwork_research_themes/projects/North_Sea_Palaeolandscapes/index.htm

An important point to derive from these developments is that the spatiality of the data itself is a major research driver and this permits visualisation development to traverse existing disciplinary boundaries (Gaffney forthcoming). All in all, there is a net benefit to archaeology in these circumstances as the cost of software development is borne by other (wealthier) disciplines and technology and experience is transferred to archaeology at a relatively low cost which, whilst still relatively high for some archaeological applications, will be affordable in many cases. There is also another benefit in that the common spatiality of data from disparate technologies provides the link that may permit a greater degree of true data fusion between technologies. The general assumption that the sum of parts will be greater than the whole has been considered by a number of recent papers (Kvamme 2006). In view of the increasing sophistication of visualisation softwares and the processing power available to geophysicists and archaeologists, the interest in data integration is likely to be a growth research area in the future. Work currently being carried out by Meg Watters as part of Doctoral studies at the University of Birmingham suggests that solid modelling softwares that can handle multivariate attribute data have much to offer in respect of remote sensing technologies that operate in 3 dimensions. Solid modelling softwares that promote spatial integration, irrespective of source, and sophisticated filtering of data from multiple sources (including traditional excavated surfaces or derived data such as site drawings) permit a radically different perception of what constitutes the interpretative context of geophysical survey **(Figure 13)**.

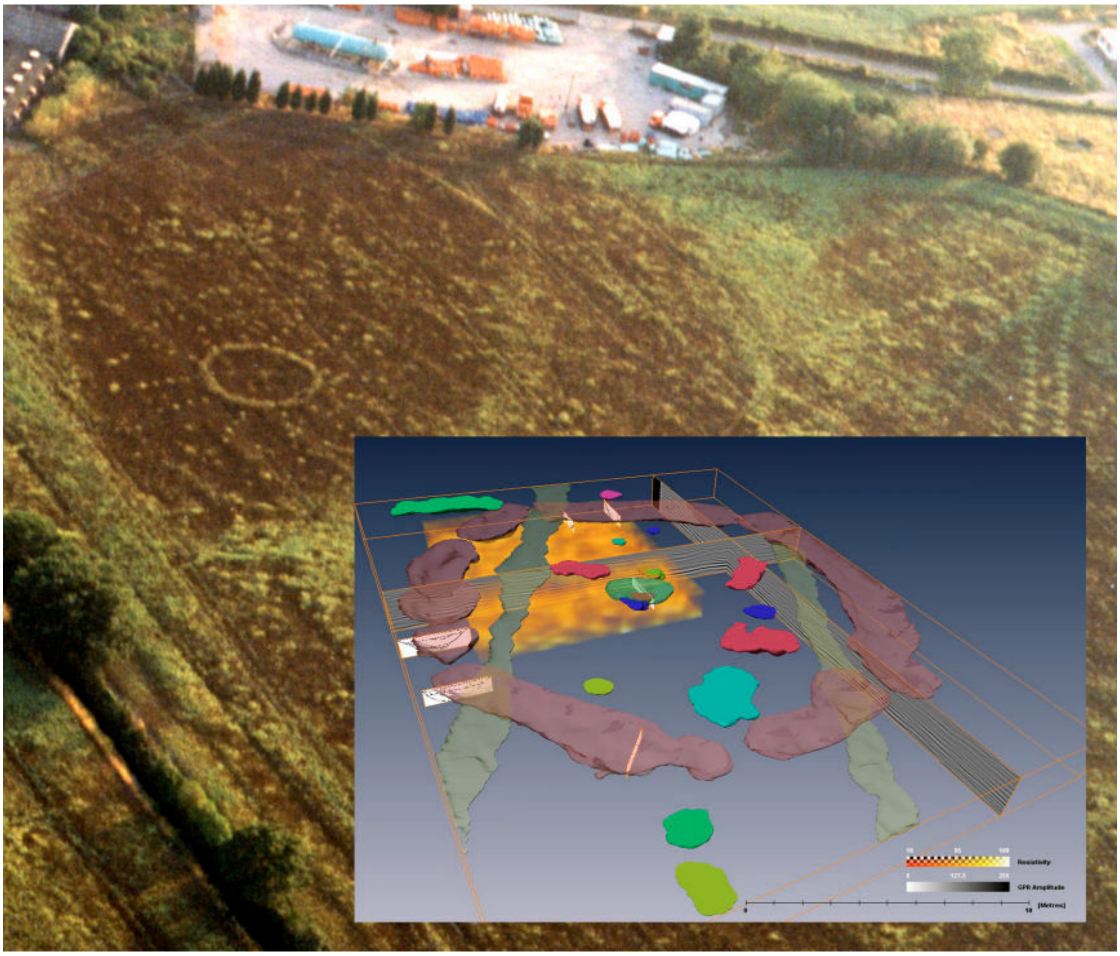


Figure 13. Crop marks and geovisualisation of the Sunburst monument from the Catholme Ceremonial Complex, Staffordshire, UK. GPR and Electrical Tomography data combined with archaeological data for enhanced archaeological feature interpretation, modelling and visualisation. Image courtesy of Meg Watters, University of Birmingham.

There is another trend that merits some comment. This relates to the increased use of enriched imagery, including virtual reality, aspects of solid modelling and augmented reality, for the purposes of visualisation of remote sensed data, their interpretation and dissemination. The translation of geophysical data into interpreted models, including structural reconstructions, is not, of course, entirely novel. However, the increasing sophistication of such models moves the issue of the interpretation of remote sensed data from the general realm of natural science and numeric process firmly into the larger domain of archaeological inference. This is not necessarily a comfortable position for many geophysicists although it does acknowledge the increasingly central role that the technologies play within archaeology. The creation of an interpretative model of buildings associated with the geophysical survey at the Roman City at Wroxeter is a case in point (Gaffney and Exon 1999). These models add significantly to our spatial appreciation of buildings that we cannot see, in the case of the majority of buildings at Wroxeter, and that we are unable to appreciate via traditional display technologies. As an aside, sensory perception within remote sensing is usually associated with visualisation but there may also be a case to consider haptics or tactile technologies as a potential area for future archaeological research. Touch, after all, is more sensitive than the eye, a relatively dull optical instrument in sensory terms, and the technology to replicate tactile experience has been used in seismic exploration for some time (McLaughlin and Orenstein 1997). The ability to haptically render remote sensing data and to produce 3 D models (perhaps in virtual clay softwares) is an attractive concept that could take current solid modelling and visualisation of archaeological remote sensed data further yet (Sener et al. 2002).

Taken altogether all these developments suggest that the future of remote sensing in archaeology looks extremely healthy. Instrumentation is improving rapidly and a number of novel technologies or significant variations of older technologies are becoming available for archaeological use. However, what may ultimately be more significant is that, for the first time for decades, processing softwares are developing in a parallel manner and now provide a sophistication in terms of analysis and visualisation that has never previously been available. It may even be that processing software may actually outstrip the ability of hardware to generate data and that the processing of the data may become more significant because of the increasing variety of options to display and interpret the data via available softwares. This trend may become more obvious with the implementation of distributed GRID technologies. For instance, geophysics processing is anticipated as one use of the Large Hadron Collider Grid, a system capable of handling Petabytes of data (http://www.pparc.ac.uk/Nw/100sites.asp). Although it must be acknowledged that archaeology was probably not at the top of the list for the design team of this particular system, we can be equally sure that archaeology, the most catholic of disciplines, will not be slow to take advantage of the opportunities provided by others at such considerable expense!

Having said this, the fundamental reason that remote sensing will remain at the heart of archaeological research is because it helps archaeologists understand their data better and contributes to the interpretative process of archaeology in an increasingly substantive manner. A final example of such a process, if the authors may be permitted a degree of self-indulgence, is provided by the Wroxeter Hinterland Project (**Figure 14**). The geophysical survey of the site was published in Archaeological Prospection as an example of remote sensing at the end of the Twentieth century (Gaffney and Gaffney 2000). For the large number of people involved it was a considerable achievement. Teams from Britain, France, Germany the USA and Japan, private companies, governmental institutions and amateur groups all contributed to this large survey which, at the time, was probably the largest ever attempted. As the first such survey of a Roman City in Britain it has provided a model for similar work in Britain, for example the current survey undertaken by Dr J. Creighton at Calleva Attrebatum, and abroad. The urban surveys carried out as part of the Tiber Valley Project spring to mind (Keay and Millett 2000).

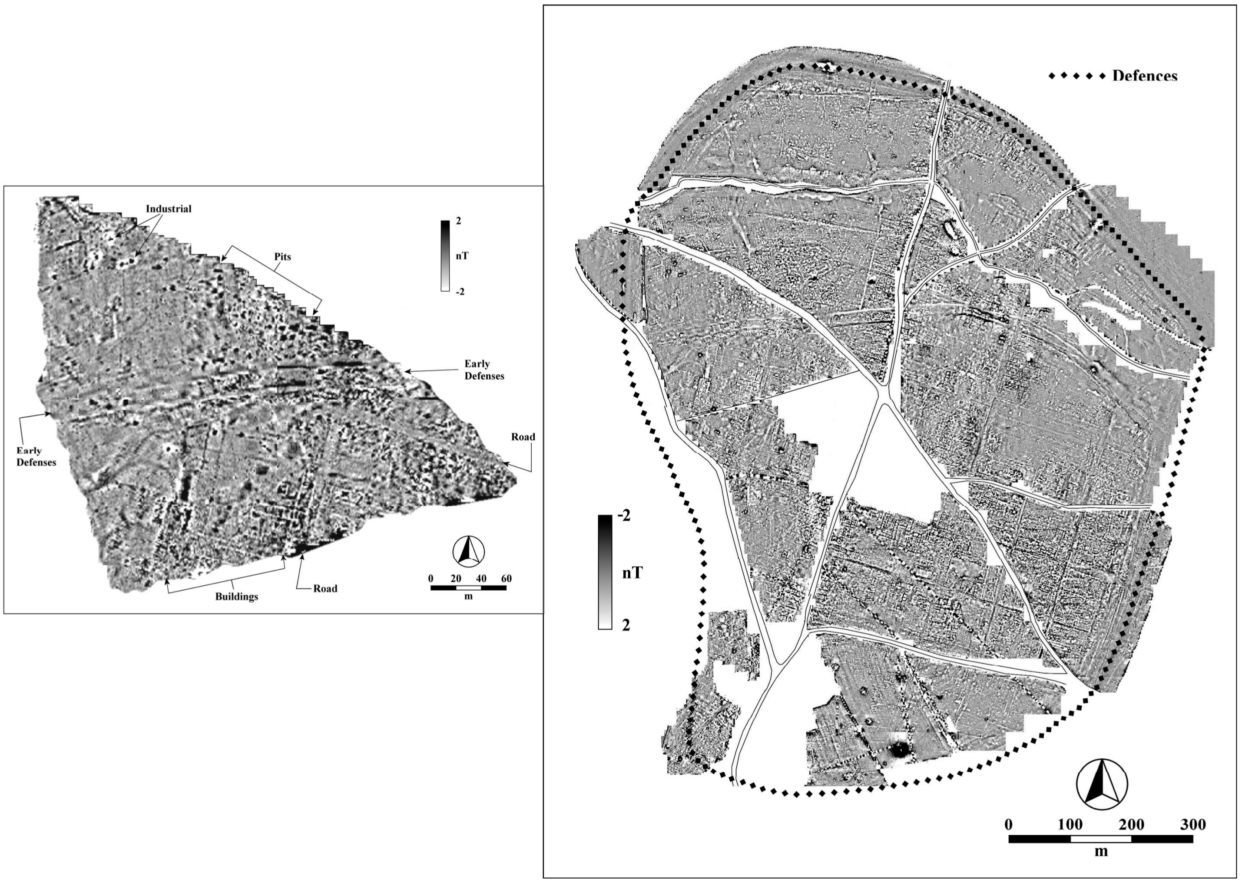


Figure 14. On the right hand side is an image of the magnetic data of the Roman City of Wroxeter collected by GSB Prospection and the AMLab using Geoscan Research FM series magnetometers. On the left hand side is detail from one of the areas. Note the change in vertical scales. The figure is after Gaffney and Gater 2003 and is courtesy of the two survey groups.

However, it is apparent that the scale of the survey at Wroxeter is not so significant in terms of the improved instrumentation now available. The magnetometer survey at Wroxeter, which formed the heart of the project, could be undertaken in days rather than weeks using currently available equipment (Gaffney C. et al 2000). However, the importance of the survey lies in its full integration with the larger archaeological project (Gaffney and White Forthcoming). It is significant that excavation on the basis of this survey was not a prime requirement of the project. This was in complete contrast perhaps to a comparable survey could it have taken place even a decade earlier. Instead the data was important in its own right as an indication of the nature of urban settlement and how this was to be interpreted in the light of a larger hinterland study. The geophysical survey provided the basis for a modelling programme to investigate the level of urban dependency on extra-mural resources and to assess urban-rural relationships in substantive manner (Gaffney and Goodchild, In Prep.). It was also notable that the data were used to provide a virtual reconstruction of buildings and phases of the site (Gaffney and Exon 1999). Whilst relatively clumsy in comparison with what can be achieved today the project was clearly a precursor to the trends we have identified above in that it promoted innovative instrumentation (Dabas et al. 2000; Barratt et al. 2000; Walker 2000), enhanced visualisation (Gaffney and Exon 1999; Nishimura and Goodman 2000) and substantive integration with the larger interpretative and theoretical framework of archaeology (Buteux et al. 2000; Gaffney and White forthcoming). In making such observations we flatter ourselves that whilst Wroxeter was indeed a project of the last century it did anticipate the trends in remote sensing that we now witness at the beginning of the 21^{st} century.

While the challenge we now faced is fundamentally linked to the scale of visualisation, this cannot be tackled unless the data are collected in the manner that Arnold Aspinall has drilled into a generation of scholars. While we cannot put our hands on our hearts and say that we know everything about a data set when we leave the field after survey, we do know that data that we collect underpin a new and challenging interpretation that knows no territorial boundaries. Whether one needs to know about an individual pit, or the place of that pit in the landscape, where would archaeology be without remote sensing and where would we all be without the contribution of Arnold Aspinall?

References

Bowden, M. (ed.) 1999. *Unravelling the landscape: an inquisitive approach to archaeology*. Stroud: Tempus.

Barratt, G. Gaffney, V., Goodchild, H., Wilkes, S. 2000. Survey at Wroxeter using carrier phase, differential GPS surveying techniques. In Gaffney C, Gaffney V. (Eds.) Non-invasive Investigations at Wroxeter at the end of the Twentieth Century. Archaeological Prospection 7,

Buteux, S. Gaffney, V. White, R. Van Leusen, M. 2000. Wroxeter hinterland project and geophysical survey at Wroxeter. In Gaffney C, Gaffney V. (Eds.) Non-invasive Investigations at Wroxeter at the end of the Twentieth Century. Archaeological Prospection 7,

Challis K. 2006. Airborne laser altimetry in alluviated landscapes. Archaeological Prospection 13, 2, 103–127.

Chapman H. 2006 Landscape Archaeology and GIS. Tempus

Conolly J. and Lake M. 2006 *Geographical Information Systems in Archaeology*. Cambridge Manuals in Archaeology. CUP.

Dabas M, Favard A, 2004. Fast imaging of a Romano-Celtic Temple with a decimetric resolution: 1 ha in 2 hours ? In Near Surface 2004, 10^{th} European Meeting of Environmental and Engineering

Dabas, M. Hesse, A. and Tabbagh, J. 2000. Experimental resistivity survey at Wroxeter archaeological site with a fast and light recording device. In Gaffney C, Gaffney V. (Eds.) Non-invasive Investigations at Wroxeter at the end of the Twentieth Century. Archaeological Prospection 7,

English Heritage 2006. Developing professional guidance: laser scanning in archaeology and architecture. Advice and guidance to users on laser scanning in archaeology and architecture. (http://www.ceg.ncl.ac.uk/heritage3d/downloads/TLS%20formats%20V1.pdf)

English Heritage 2006b. An Addendum To The Metric Survey Specifications For English Heritage - The Collection And Archiving Of Point Cloud Data Obtained By Terrestrial Laser Scanning Or Other Methods. (http://www.english-heritage.org.uk/upload/pdf/metric_extraction_scanning_addendum_2.pdf)

Fisher PM. 1998. Applications of Technical Devices in Archaeology - the use of x-rays, microscope, electrical and electromagnetic devices and subsurface interface radar. Studies in Mediterranean Archaeolgy LXIII.

Fitch S., Thomson and V. Gaffney. 2005. Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. Quaternary Research 64, 185-196.

Fuller PR, Hill IA and Leech C. 2006. A Comparison of Archaeomagnetic Results from a Towed Magnetometer Array and Traditional Methods. ISAP Newsletter 7:7-9

Gaffney C, Gaffney V. 2000 Non-invasive Investigations at Wroxeter at the end of the Twentieth Century. Archaeological Prospection 7:65-67.

Gaffney, C. F., Gater, J. A., Linford, P., Gaffney, V. L. and White, R. 2000. Large-scale systematic fluxgate gradiometry at the roman city of Wroxeter. In Gaffney C, Gaffney V. (Eds.) Non-invasive Investigations at Wroxeter at the end of the Twentieth Century. Archaeological Prospection 7,

Gaffney C, Gater J. 2003 Revealing the Buried Past: geophysics for archaeologists. Tempus

Gaffney V. Forthcoming. In the Kingdom of the Blind: Visualization and E-Science in Archaeology, the Arts and Humanities. Paper presented to the AHRC Expert Seminar – Virtual History and Archaeology – Subject 1 – Sheffield, Wednesday 19th April, 2006

Gaffney V. and Goodchild H. In Prep. Feeding the City.

Gaffney V. and White R. Forthcoming. *The Wroxeter Hinterland Project: Wroxeter, the Cornovii, and the Urban Process.* Journal of Roman Archaeology Monograph.

Gaffney V., and Exon S. 1999. From Order to Chaos: Publication, Synthesis and the Dissemination of Data in a Digital Age. *Internet Archaeology* **6**, http://intarch.ac.uk/journal/issue6/gaffney_toc.html

Leckebusch J. 2005 Precision real-time positioning for fast geophysical prospection. Archaeological Prospection 12:199-202.

Johnson M 2006, Ideas of Landscape. Blackwell

Kvamme K. L. 2006. Integrating Multidimensional Archaeological Data. Archaeological Prospection 13, 57–72.

Keay, S., Millett, M.. 2000. Falerii Novi: A New Survey of the Walled Area. *Papers of the British School at Rome 68*: 1-93.

McLaughlin, J.P. and Orenstein, B.J., 1997, Haptic rendering of 3D seismic data; Second PHANToM User's Group Workshop Proceedings, Boston.

Nishimura, Y and Goodman, D. Ground-penetrating radar survey at Wroxeter. Archaeological Prospection 7,

Sener B. Wormals P and Campbell I. 2002. Evaluating a Haptic Modelling System with Industrial designers. Proceedings of the EuroHaptics 2002 International inference, 165-169 http://www.pedgley.com/baharsener/metu/BaharSener-Eurohaptics2002-full.pdf)

Tilley C. 1994. A Phenomenology of Landscape: Places, Paths and Monuments. Oxford, Berg..

Walker R, Linford P. 2006 Resistance and Magnetic surveying with the MSP40 Mobile Sensor Platform at Kelmarsh Hall. ISAP News 9:3-4

Quann J. and Bevan B. 1977. The Pyramids from 900 kilometers. M.A.S.C.A. Newsletter, Vol. 13. pp. 12-14.

