The Landscape
Research Centre

Beneath the sand: Remote Sensing, Archaeology, Aggregates and Sustainability

A case study from Heslerton, the Vale of Pickering, North Yorkshire, England

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Introduction

The landscape centred on the village of West Heslerton, on the southern side of the Vale of Pickering, has been the setting for one of the most ambitious projects in landscape archaeology undertaken in Britain. Large area excavations covering more than 22Ha, 25 years of air photographic survey, two large area multi-spectral and vertical photographic surveys, a Laser Imaging Detection and Ranging (Lidar) survey, nearly 1000Ha of contiguous gradiometer survey and a 200Ha sub-surface mapping auger survey, have revealed the most comprehensive body of archaeological landscape evidence for any area of its size in Britain.

The majority of the evidence already gathered covers an area of alkaline sands and gravels following the southern edge of the Vale of Pickering, and work is in progress focussing attention on the sands and gravels in the flood plain of the Vale of Pickering. In this area geophysical responses are different but when combined with other sources are providing methods of isolating areas of archaeological interest, including crop-marks, relict stream channels and fragments of surviving peat deposits (which offer the potential for the recovery of the environmental evidence so desperately lacking in the alkaline sand and gravel areas).

The combined dataset derived from more than 25 years of rescue and research archaeology, mostly funded by English Heritage, and, in particular, the recent geophysical and sub-surface survey, funded by the Aggregates Levy Sustainability Fund (ALSF) through English Heritage, offer the potential to assist in the development of approaches to the extraction of aggregates that secure the sustainability of the archaeological resource. In order to develop a pro-active approach to managing the archaeological landscape, simply knowing it is there is not enough, if intelligent decisions are to be made then the sheer quantity of known archaeology must be set against the chronological depth and in particular to the 'quality' of the resource. Nowhere is this more important than in buried landscapes whether covered by colluvium, alluvium or aeolian sands.

This paper discusses the results of this massive project, the various methodologies applied in an attempt to discover the 'real' archaeology of the Heslerton research area, and issues regarding archaeological 'quality' with reference to the sustainability of the resource within an aggregate bearing landscape.

Context

The area around the villages of East and West Heslerton on the southern side of the Vale of Pickering, North Yorkshire, England, has been the focus of an ongoing and intensive programme of archaeological research following the accidental discovery of an early Anglo-Saxon cemetery during sand and gravel extraction at Cook's Quarry, West Heslerton in 1977 (Figure 1). The discovery, during removal of overburden comprising plough-soil and a sealing layer of aeolian sands, was one of many unexpected major sites discovered in Britain during aggregate extraction in the 1960's and 70's. The discovery prompted a rescue excavation, funded from the public purse, by the Department of the Environment (now English Heritage) and provided the setting for the development of a long term research project combining large scale rescue excavations with broader research into the landscape context of the excavated areas (Powlesland *et al* 1986).

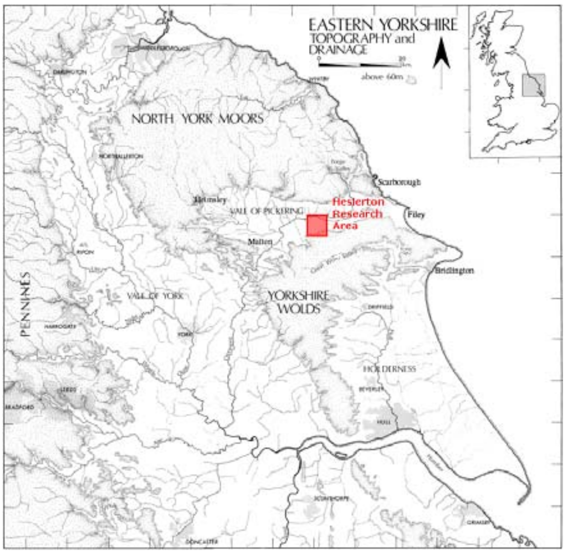

Figure 1: Location of the Heslerton Research Area on the southern side of the Vale of Pickering, North Yorkshire, England.

The light soils so characteristic of the aggregate bearing subsoils found in the valleys and river terraces of lowland England were ideally suited for prehistoric and later settlement and agriculture and thus provide the setting for the highest density of archaeological activity in Britain. Aggregate extraction is by its nature totally destructive of the archaeological resource, and poses particular problems on account of the often very large areas of ground affected and the relationship between the sands and gravels and the past patterns of use of these areas. Although excavation and recording programmes funded by the quarry operators, through arrangements established under PPG16, have replaced the large rescue projects funded from the public purse, the discovery of unexpected and nationally or internationally important archaeological sites during aggregate extraction has continued to pose significant problems both for archaeology and the aggregate industry. The greatest challenge for planners, aggregate operators and archaeologists, is created by the lack of detailed knowledge as to exactly how much archaeology there is. It is important to realise that the contents of the nations Sites and Monuments Records, the primary basis upon which planning conditions relating to archaeology are set, are derived from *ad-hoc* evidence, almost all of which has also come to light through accidental discovery in the past. Air photographic records, which have revealed much in aggregate landscapes in particular, are likewise *ad-hoc* in nature relying upon air photographers being in the right place at the right time to be able to record crop-mark evidence; evidence which appears in response to a complex combination of crop, soil, long term climatic and lighting conditions.

It became very clear during the initial rescue excavations at Cook's Quarry, West Heslerton, that our understanding, comprehension and ability to interpret the excavated evidence was compromised by the lack of information that allowed us to place the 'site' in its landscape context. Moreover it was also appreciated that investment in this one excavation reflected a deliberate decision to examine this 'site' acknowledging that others would lost at the same time without record. The conscious decision to concentrate efforts in Heslerton reflected the realisation that the site was significant not only on account of the multi-period and multi-faceted archaeological deposits, that would otherwise be lost without record, but also because, blown sands had buried the archaeological features over large areas of the 'site' in a manner not commonly found in Britain. These blown sands had for instance, preserved an upstanding Early Bronze Age barrow, which it appeared, had not been seen since the Roman period; it was not simply another quarry site with already ploughed out multi-period settlement and funerary activity, and made the 'site' exceptional.

In 1980 the Heslerton Parish Project (HPP) was established to define a research strategy within which to frame the ongoing excavations (Powlesland 1980, 1981, 2001, 2003a). It was amongst the first major projects in what was then the emerging discipline of 'Landscape Archaeology'. The project was driven by the need to establish the landscape context of the large multi-hectare and multi-period excavations then in progress. Our ability to interpret the, in reality, very small sample excavations was compromised by a lack of comprehension of the contemporary landscape beyond the trenches. The Vale of Pickering, with the exception of the major Late Palaeolithic/Early Mesolithic sites at Star Carr and those being examined by Tim Schadla-Hall at Seamer Carr on the margins of the ancient Lake Flixton (Schadla-Hall 1987a, 1987b, 1988), the Late Bronze/Early Iron Age palisaded enclosures excavated by Tony Brewster at Staple Howe and Devil's Hill (Brewster 1963, 1981), the Roman centre at Malton, medieval manorial elements examined by Brewster in Sherburn and Potter Brompton (Brewster 1952) and some Romano-British and Early Anglo-Saxon settlement at Seamer, Cross Gates (Pye 1976, 1983), evidence was largely blank in maps reflecting the archaeology of almost any period. It was argued in the research design that prehistoric and later land-use and settlement patterns were to a large extent environmentally determined, using environment in its widest sense combining soils, climate, vegetation and ground water conditions and proximity to other ecosystems supporting hunter gathering and transhumance systems (Powlesland *et al* 1986, 1987a, 1988). The landscape of the southern Vale of Pickering and the northern edge of the Yorkshire Wolds can be readily assigned to a number of distinctive eco-zones, which extend both to the east and west of the core research area covering the parishes of East Heslerton, West Heslerton and Sherburn. The research design argued that we should view the evidence in plan, visualised on a transect extending south to north from the Gypsey Race in the Great Wold Valley to the River Derwent, so that the distribution and density of activity could be mapped according to the primary eco-zones based on soils, elevation and proximity to 'off-site' resources. It was further argued that the existence of the same eco-zones both to the east and west of the main research area should allow the data to be viewed as a testable reference sample across the landscape.

A holistic approach to an archaeological landscape

In order to provide the landscape context of the excavations and build a spatial, chronological, social and economic model of landscape development we needed to be able to identify the archaeological resource. A programme of remote sensing and other fieldwork was begun during the first excavation season at Cook's Quarry in 1977. From the outset it was argued that a holistic approach to investigating the landscape should be adopted employing whatever methods were available to build up a complimentary body of evidence from multiple sources. This view still lies at the core of the rescue and research philosophy of the Landscape Research Centre (LRC). In reality it has only been possible to build what we could term a holistic dataset through a large number of different projects funded from different sources over more than 25 years. Over this period the approach has constantly evolved in response both to discovery and also to changes in technology, particularly with reference to remote sensing, field recording, dating and GIS technologies (Powlesland 1986, 1987b,1991). Whether it be improved instruments for multi-spectral imaging, the development of 'intelligent' total stations, better C^{14} dating or entirely new technologies such as high precision GPS, Lidar or 3D Scanners each technology has been assessed to see what it can add to the dataset, rather than simply to replicate something that could already be done using established technologies.

The building and use of the Heslerton Landscape Dataset without modern up-to-date computers would have been entirely impossible, as it combines multi-sensor remote sensing data of different types and at different resolutions, multi-excavation databases, plans, interpretive drawings, dating and stratigraphic sequencing models, finds and environmental evidence within a single linked resource. Although a wide range of different software tools are utilised for different applications the projects have benefited from data integration provided through the application of GIS technologies for more than 20 years. The excavation database sits at the core of the dataset, linking every aspect of the dataset through the use of a unique key identifier or Key_ID; a single structure is used for all context records, another for all finds and another for all the remote sensing evidence. Interpretive plots identifying all features uniquely are prepared as overlays to the geophysical, rectified air-photographic and multi-spectral images, this is of fundamental importance given the need not only to apply different research technologies but also to be able to quantify, compare and contrast the returns from different methods.

Air photography the primary remote sensing resource

Air photography from a light aircraft with a hand-held single lens reflex camera is relatively cheap, can cover large areas, can produce splendid results and is fun to do. An *ad-hoc* programme of air photography was begun in 1977 and continued with varying frequency on an annual basis. We were particularly fortunate that one local farmer, Karl Wilkinson, had a high wing Cessna, from which he was happy to remove the door and was willing to fly at almost any time. Despite the often poor conditions for air photography in the Vale (which is liable to sea mists or frets which often reduce visibility at exactly the time when crop-marks would be showing at their best) by 1980 a large number of crop-mark 'sites' had been identified. Our own air photographic record was enhanced with new 'sites' being added on an annual basis following flights by other air photographers. Even as recently as 2005 major new crop-mark complexes have been added to the record despite saturation of the crop-mark coverage having been effectively achieved over most of the area by the early 1990's.

The most distinctive feature identified through the air photography is a linear settlement zone following a wetland edge trackway complex, termed a 'ladder settlement', on account of the appearance of the strips of joined rectangular enclosures, ran from east to west right through the research area, although it had numerous gaps where crop-marks were not detected. Fragments of a similar complex have been observed in crop-marks on the northern edge of the Vale, but this area has not been setting for the type and intensity of study devoted to the Heslerton area.

The blown sand deposit that makes the research area unique, is in places more than a metre deep and can be traced for more than 10km, along the southern side of the Vale of Pickering. However by 1980 the role played by the blown sand in concealing buried archaeology from the visible landscape and its potential to restrict crop-mark formation was recognised.

Geophysical survey, the excavation context

Trial geophysical surveys using gradiometery at Cook's Quarry in 1980 and again using resistance methods near Sherburn in 1984 failed to produce good or even convincing results. Had the initial geophysical survey results been taken as indicative of the general potential, work on this front may have stopped at this point; however, following the immensely successful gradiometer survey carried out by English Heritage ahead of the West Heslerton: Anglian Settlement Excavation in 1989, we purchased our own gradiometer, the results from which have been outstanding.

Initially our attention was focussed on the application of gradiometery within the context of the excavation. It was argued that high resolution gradiometery undertaken during the excavation process, following the removal of the disturbed plough-soil and at a ground resolution of .25 x .25m, should give highly detailed results that could be used to assist in developing the excavation strategy (Figure 2) (Lyall and Powlesland 1996). The survey showed that without the masking influence of the disturbed plough-soil, post-holes and minor features as well as structure and sequence in ditch complexes that could at first barely be seen on the surface, were clearly visible.

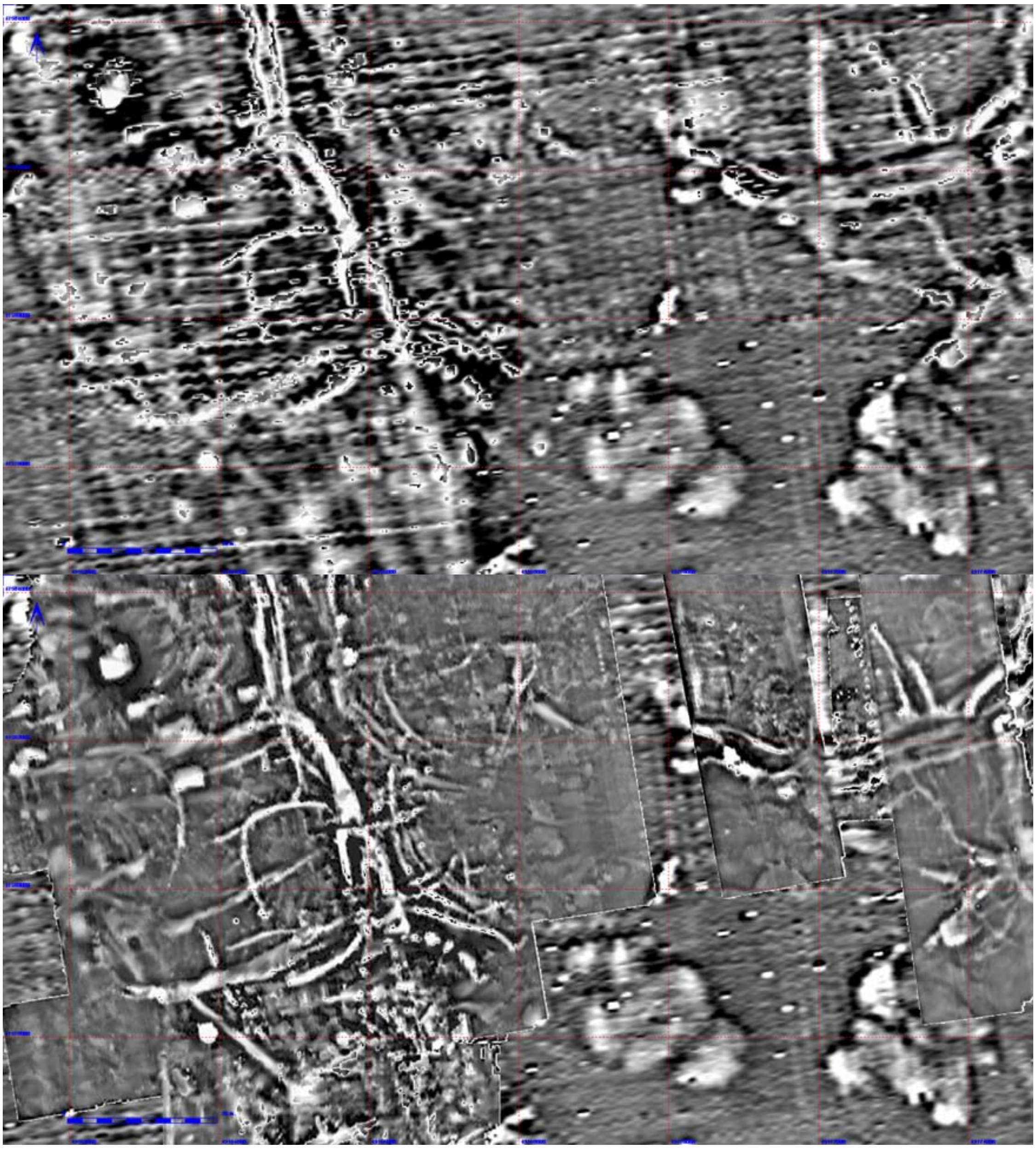

Figure 2 Gradiometer survey results gathered before removal of overburden at 1 x .25m resolution above and the same area below with areas gathered at .25m x .25m resolution after removal of the overburden prior to excavation, West Heslerton Anglian Settlement. Data collected by English Heritage, upper image, LRC lower image.

Multi-spectral imaging

Whilst attention was directed towards the large scale (13Ha) excavation of the West Heslerton Anglian Settlement there was little opportunity to apply magnetometry to the wider landscape, air photography continued as and when the opportunity arose both to document the excavations from the air and to identify further crop-marks. Although many crop-marks appeared repeatedly the number of new discoveries reduced over time, with the occasional exceptional new discovery which, in one case, could be linked with a deeper ploughing event in the previous year, so that an apparently blank field produced a large complex of clear and extensive crop-marks.

The patchwork nature of the air-photographic plots, with clear gaps in what appeared to be extensive and coherent crop-mark complexes, indicated that we were not seeing the full picture - some fields were permanent pasture, in others it was felt that the blown sand sealing the deposits was effectively reducing the potential for crop-mark formation. If we were to increase the knowledge base new approaches were required which were either more sensitive to crop luminosity and reflectance than conventional 35mm oblique photography, or employed wholly different techniques to map the buried resource.

In 1992, in collaboration with Durham University, Department of Geography, the Landscape research Centre was awarded a NERC remote sensing grant and the area was flown capturing high resolution 12 band multi-spectral data and high resolution large format vertical photography (Donoghue and Shennan 1988a, 1988b, Donoghue *et al* 1992, Powlesland *et al* 1997). The singular difference between the NERC survey and previous oblique air photography was the edge-to-edge coverage, the returns from the high resolution vertical photography were outstanding, far better than had been anticipated. It had originally been planned to undertake the survey flight early in the growing season to look for both soil marks and germination marks; in the event the flight was delayed until June when large areas of crop-marks showed clearly. The multi-spectral data, although of lower resolution than one might wish for, not only showed the features seen in the air photographs but also a considerable amount of new information or additional detail in the infra-red and thermal wavelengths.

Geophysical survey, beyond the excavation
Following the completion of the large excavations in West Heslerton in 1996 and the initial post-excavation and analysis, there was time to develop new projects. A series of tests using the gradiometer revealed that the sands and chalk gravels which lie beneath the blown sands and the chalky areas at the foot of the Wolds were highly responsive to geomagnetic prospection techniques (although the magnetic contrast was reduced for features earlier than the Late Iron Age). Reduction of the magnetic response caused by the blown sands was far less evident than we had anticipated and it was clear that this method could greatly enhance the picture that had emerged from the airborne surveys.

Since 2000, four different English Heritage funded projects have contributed to a radical new understanding of the landscape. A large area (c.350Ha) geophysical survey covers the area from the lower slopes of the north face of the Yorkshire Wolds to the edge of the ancient wetland areas in the base of the valley between the villages of East Heslerton and Sherburn 3.2km to the east. The geophysical survey has been undertaken under the supervision of James Lyall, assisted by Heather Clemence, Katherine Day, Maria Beck, David Stott, Peter and Ben Wilson, Glenn Paterson, Will Hinchliffe and Chris Fern. This project was designed to identify the distribution of settlement, field, and burial activity between the foot of the Wolds, establish a basic chronological sequence and determine whether the combined air and geophysical survey evidence was comparable with the evidence excavated at various locations in West Heslerton (Figure 3).

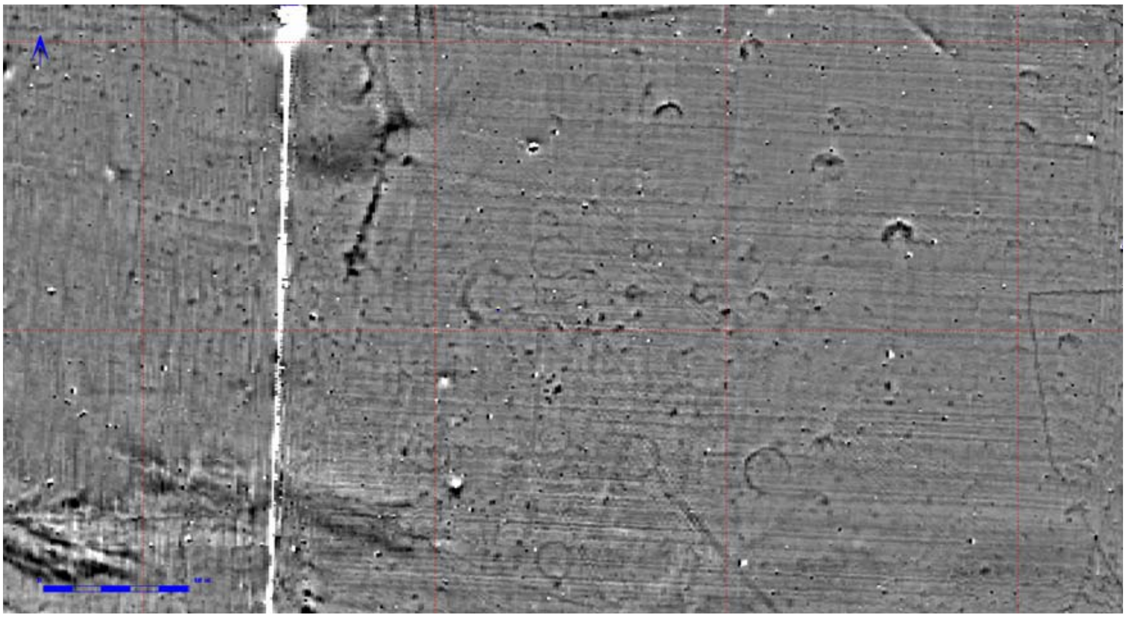

Figure 3. Parts of a late Prehistoric barrow cemetery discovered in the initial large area geophysical survey comprising ring ditches ranging from 10-25m in diameter.

There is insufficient space here to discuss in detail the results of the large area surveys and it would also be premature given the limited nature of the ground truthing exercises so far undertaken. However, with approximately 20,000 features identified over an area of about 5,000 Ha, 16,000 of which are derived from the geophysical surveys covering nearly 1000 Ha, the results have been spectacular. An example showing the distribution of Anglo-Saxon *Grubenhäuser*, features that have recognisable and distinctive geophysical characteristics and are amongst the few anomalies that can be classified without hesitation in the geophysical survey data, demonstrates the nationally important nature of the results (Figure 4). Nowhere else in England has such a dense cluster of Early Anglo-Saxon settlement evidence been identified, even if we exclude those clusters that may be Middle Saxon, the evidence indicates that the huge excavated settlement at West Heslerton is one of a number similar sites reflecting a density matching that of the present villages, moreover these large settlements have to viewed against an even greater frequency of smaller sites comprising 20-50 buildings which follow the Late Iron Age and Roman 'ladder settlement' at roughly 800m intervals (see below) (Powlesland 1991,1998a, 1998b, 2000, Haughton and Powlesland 1999).

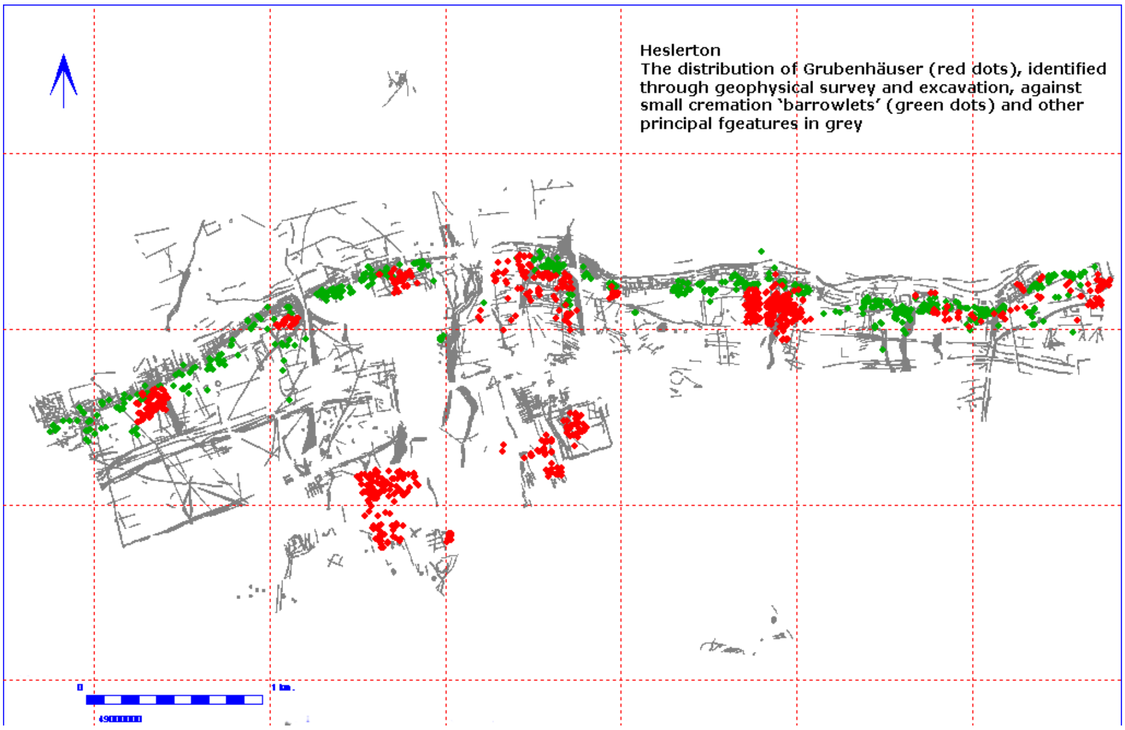

Figure 4. The distribution of Anglo-Saxon *Grubenhäuser* identified across all geophysical surveys

The results are spectacular but require testing through excavation, in particular to examine the blown sands, problems arising from plough damage which is exacerbated when the plough cuts through the relatively hard and compact blown sands into the softer archaeological deposits beneath and to examine some apparently 'new' classes of features.

Analysis of the blown sand

A small excavation (DigIT project) comprising three very restricted trenches was conducted in 2001, this allowed us to examine the blown sand in detail, assess the degree of plough damage and test a range of different features identified in the survey whilst at the same time undertaking a detailed review of digital recording techniques (Powlesland & May, forthcoming). The DigIT project incorporated a detailed study of the blown sand over part of the Late Iron Age and Roman ladder settlement; it is an amorphous deposit of red-ochre sand, sometimes with thin clay varves running through it, which at first glance may be considered not worthy of careful excavation. The blown sand deposit, which at this point was up to .3m thick beneath a .3m thick plough-soil, was carefully troweled away and all finds individually three- dimensionally plotted. Subsequent analysis reveals that although there is little visible structure in the deposit the distribution and fragmentation of the finds demonstrate a gradual build-up over the top of the debris from the deserted ladder settlement. Here the blown sand appears to have accumulated from the Roman until the Late Medieval period. A group of Iron Age sherds recovered from the upper few centimetres of the deposit may be derived from areas of plough damage occurring near by (Figure 5).

At Cook's Quarry it was clear that the blown sand was a characteristic of the late prehistoric landscape, initially becoming mobile during or before the Late Mesolithic (probably very much earlier) and that it formed moving dunes which sealed old ground surface fragments from the Neolithic until the Late Iron Age. The evidence from the detailed study seems to indicate that during the Post-Roman period the ground levels must have risen very gradually, presumably whilst the area was being ploughed the organic components within the lower plough-soil leached out, reducing what must at times have been a plough-soil back to its principal blown sand component. Reworking of the soil during the period of build-up has removed any clearly defined stratigraphy within the deposit. Observation work associated with the laying of a new water main, to the east of Sherburn, revealed a number of locations where stratified deposits could be identified within the blown sand, confirming that the formation and de-formation processes involved are neither simple or uniform throughout the research area.

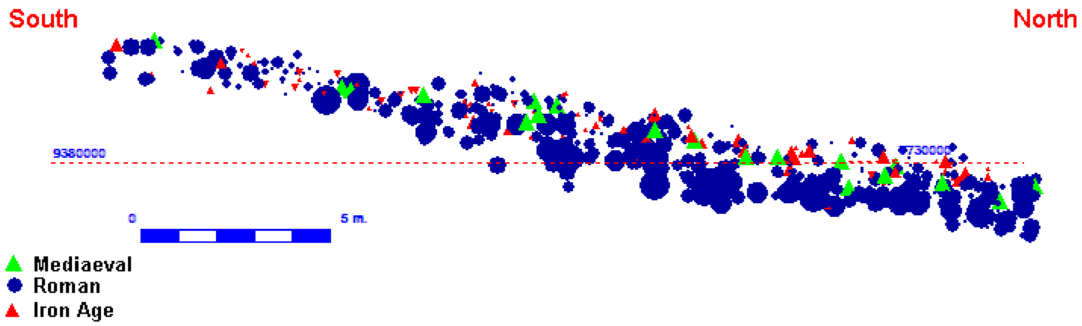

Figure 5. Sectional view of the ceramics distribution in the blown sand in DigIT Area 028AC (dots sized by weight) (Z magnified x 10*)*

Problems of terminology

As the geophysical survey developed it became clear that the term 'site' with its connotations of dots on maps and isolated features in the landscape reflected poorly on the reality in which the whole landscape was the site. A barrow or settlement complex for instance did not exist in isolation, either from events happening elsewhere in the landscape, chronologically before its existence, or from the space around it. The vast amount of new evidence emerging from the geophysical surveys in particular and the lack of chronological reference to most of the mapped evidence meant that simple or traditional feature-based databases, whilst useful for quantification and mapping clearly classifiable features such as Anglo-Saxon *Grubenhäuser*, and suitable for internal use within the LRC, would mean little to those planning aggregate extraction or to landowners. In LRC projects the term 'Site' is synonymous with field, with each site covering a field as it is defined when survey or other fieldwork is initiated. In order to bring together the evidence from all archaeological research in any single field the results are compiled to form standardised Site Dossiers which include narrative descriptions of all work undertaken, the interpretation of the results, and the supporting evidence. The Site Dossiers now exist for every field in which evidence has been recorded.

The Site Dossiers have been designed to support the long-term management objectives through distribution to the individual 'Landkeepers' (this may be the owner or a tenant and often both) and as supporting evidence to the county Sites and Monuments record. We need to clearly acknowledge the role of the Landowners and Landkeepers in securing the long-term future of the archaeological resource, as none of the work undertaken in and around Heslerton can be completed without their support and cooperation. By providing field-by-field datasets that can be incorporated into farm records we hope not only to nurture interest in the land and its past but also to make the case for preservation and management as and when it is necessary.

Assessment of 'quality'

The survey results when considered in relation to the small excavations undertaken as part of the DigIT project raised important issues regarding the 'quality' of the archaeology identified through remote sensing and the need to inform the long-term management process. Within the research area we will neither be able to preserve all of the archaeological resource or do justice to those areas that get destroyed through preservation by record (the costs of which, in an intensively farmed rural landscape, defy calculation). If we are to secure sustainability of the archaeological resource then we need to understand the nature and potential of the resource before we can determine which parts of the resource are most worthy of long term management.

In the 1960's and 70's many outstanding crop-mark sites were afforded some legal protection through scheduling in the belief that we were preserving the best examples. However, we now understand that many of these crop-marks were outstanding on account of the amplification of the crop-mark formation process resulting from very high contrast between the buried ditches and other features and the natural into which they were cut, as a result of truncation through plough damage. Little thought was given to trying to find less damaged parts of these crop-mark complexes in adjacent areas where the crop-mark returns may have been less visible but were better preserved.

To assign 'quality' as an attribute of the archaeological resource may seem a hopelessly subjective approach. However, the distinctive characteristic of the archaeology of the research area, with the high levels of stratigraphic survival beneath the blown sands facilitating the preservation of whole monuments, from round barrows, to surviving sealed floor deposits in prehistoric and later settlement complexes, can be assessed on a quantative basis. The survival of floor deposits and old land surfaces in rural settlement sites is very much the exception and it is the degree of survival and therefore our ability to intelligently interpret the results of excavation, which drives our interpretation of 'quality'. In addition to the survival of the physical and visible stratified deposits other aspects of 'quality' relate to the survival of faunal evidence and environmental evidence either on site or in a nearby offsite location.

During the 1970's when work begun in Heslerton the 'sand-fields' on the alkaline sands and gravels with their relatively sterile capping of blown sand were considered of poor agricultural quality, the very poor soils produced unreliable and usually poor yields. A change in the focus of agriculture and the extensive use of irrigation made these fields suitable for increasingly mechanised production of root crops, with associated deep ploughing and furrowing caused by the machines used to lift the crops is having a devastating effect on the buried landscape. The DigIt project revealed tremendous variability in the extent of plough damage over a single field and that a single year of root cropping left broad plough scars cutting 15cm into the archaeological features.

The need for better informed survey results to support the objectives of the ALSF

When the ALSF was introduced in 2002 it was realised that whilst our air-photographic, multi-spectral and geophysical survey plots demonstrated a completely unanticipated density and complexity of archaeological evidence it was simply a plot. The plot demonstrated density and spatial variation in the buried archaeological evidence but was without any information regarding the relative survival of the buried deposits or, beyond basic classification, a detailed chronological framework. If any attempt was to be made to build a dataset that could be used to assist in developing a more archaeologically sustainable approach to aggregate extraction it was critical to identify those areas that were best preserved and those that were already under serious threat or damaged by agriculture.

If we were to develop an approach to archaeologically sustainable aggregate extraction we needed more complete evidence than we could provide for the areas already surveyed. It was agreed with English Heritage that the active survey project should be suspended and a more comprehensive survey applied to the area between East and West Heslerton centred on the active Cook's quarry where the work in Heslerton began. In addition to contiguous geophysical survey undertaken under the supervision of James Lyall, assisted by Maria Beck and David Stott, an auger survey, supervised by Guy Hopkinson assisted by Aidan Harte, was undertaken to map the depths of the buried deposits and thickness of the blown sands, as these had a bearing on the potential survival of the sub-surface evidence and on the response of the various remote sensing technologies applied. Whilst the geophysical surveys revealed field upon field covered with features the auger survey was intended to map the extent and variability in depth of the blown sands and plough-soils.

In addition experiments were undertaken to examine the nature of the evidence in the topsoil and a number of observation trenches were opened simply to observe the condition of the buried resource. This project was amongst the most ambitious so far undertaken in Heslerton comprising c550 Ha of .25m x 1m gradiometer survey, examining nearly 2,500 auger cores, nearly 300 Ha of high precision topographic survey data, gathered using a vehicle mounted Kinematic GPS system, and the stripping of more than 1 km of observation trenches. The exceptionally dry conditions that prevailed throughout the eighteen month duration of the project meant that it was possible for a single team to undertake the geophysical survey within the times when the land was available for survey. However the dry conditions made the auger survey extraordinarily difficult, and the observation trenches, which could only be excavated during the short period between the harvest and re-planting, were less successful than we had hoped as the ground was so dry and the sand so well bonded that the exposed areas were like concrete to work.

The auger survey had a second objective, in the area to the north of the lower spring line, which emerges at the boundary of the alkaline sands and gravels which slope gently down from the foot of the Yorkshire Wolds to the flood-plain, a completely different deposit of glacial sands and gravels, clays extend to the River Derwent. This area had once been covered with extensive deposits of peat some of which survives either as infill in relict stream channels or small relict lakes and occasionally in archaeological features. Augering in this area allowed us to map the northern limits of the blown sands and also to identify areas of peat that would be compromised by the localised drop in the water-table associated with aggregate extraction. The importance of these peat resources should not be underestimated as they have the potential for the recovery of environmental evidence, particularly pollen and plant.

Environmental evidence of this type is conspicuous by its absence in the excavated areas and it is likely, most of the areas covered with dense complexes of mapped features. Analysis of the offsite pollen offers the potential to add environmental context to the enclosures, fields and cemeteries emerging through the remote sensing programme. A recently completed pilot project undertaken to sample and test the potential of the palaeochannels and archaeological features identified in the flood-plain from the air for the recovery of good and dateable environmental evidence has produced promising results. The dating of some of the features indicates that there was more activity in the floodplain from the later prehistoric period onwards than we had thought. The present topography of the floodplain, which has been documented using both high precision Kinematic GPS and more recently through a far more extensive Lidar survey, is problematic and it seems that the present land-surface may have dropped over large areas as the deeper peats have dried out.

Extending the Geophysical survey

Whilst the first large area geophysical survey was planned to take place over a five year programme, and now due for completion in 2006-7, the ALSF survey was larger and constrained such that the work needed to be completed within 18 months. For this to be possible at all required careful planning and liaison with the many landowners, tenants and small-holders. Fields under permanent pasture which could be surveyed at almost any time were identified and reserved so that they could be surveyed whilst there was no access to the large areas under crop. The majority of the area was being actively farmed, the fieldwork took place from September 2002 and was completed in February 2004 and provided just sufficient opportunity to cover every field without impacting the farming programme. The completion of the survey was only possible on account of the flexible approach by the farmers who on many occasions changed their short term agricultural programmes to ensure that our surveys could be completed.

Once access to the field was established, the established LRC geophysical methodology was applied throughout the project zone. Gradiometer data was collected using a standard 30m by 30m grid, each survey was begun in the southwest corner of each field. The grid was aligned either on the southern or western boundary using an optical square and ranging rods. This approach was adopted as it was fast, flexible and reasonably accurate whilst the GPS deployed gathering surface survey data and location data for the auger survey.

The early stages of this project were conducted using a pair of Geoscan FM 36 fluxgate gradiometers and a team of three people. A dual sensor, Bartington Grad 601-2 fluxgate gradiometer was used for the later stages of the survey. This became the preferred instrument as it allowed more rapid coverage (with less walking), had a far greater data capacity and faster data download rates. The quality of the data collected was also of slightly better quality, more consistent, quicker and easier to process as thermal drift is negligible compared to the older instruments. This was especially noticeable in the surveys in which two FM gradiometers were used together. The older of the two machines is more prone to drift, meaning that it was very difficult to process the combined sets of data from a single field at the same time. Collection of the gradiometer data remained at consistent resolution throughout. The standard resolution is 0.25m north-south by 1m east-west. Some small areas of high resolution data (0.25m by 0.25m) were also collected for experimental purposes. All data was downloaded in the field as and when required, and at the end of each day. All data was archived in ASCII files which include basic metadata as well as the raw data. Data processing was undertaken using G-Sys (GIS software developed by Dominic Powlesland to integrate and manage the Heslerton data), the processed results being stored in 8-bit greyscale TIF files with a ground resolution of .25 x .25m georeferenced to the GetMapping.com base map (see below).

Once processing and georeferencing had been completed each field was printed out at a scale of 1:1000 and a traced overlay drawn on draughting film. The polygons defined in the tracings and identifying each anomaly were then digitised by hand at high resolution using a digitising tablet at which time the attributes for each anomaly and the Key_ID were entered, into the digitised drawing and the associated database (Figure 6). The digitising was all undertaken by James Lyall, a process which drew on his very considerable experience assuring consistency of results, whilst the rest of the team continued with further data collection and compilation of the additional data required to build each site dossier. A series of tests revealed that it was far more difficult to digitise accurately on-screen, as many features were very difficult to follow where boundaries often lacked the clarity of the printout, than to digitise from a film overlay. It was also easier to establish consensus in areas of uncertainty on the film overlay that could easily be checked if it was noticed on screen that features had been missed. Although the film plots were the primary record used for this purpose, the raw data was also displayed on screen throughout the tracing, and could be re-processed on the fly in several different ways to clarify any areas of confusion.

In addition to producing high resolution plots of individual fields, a large plot at 1:1000 scale and covering the whole survey overlain on the Getmapping.com base map, known as ‘the wallpaper’, was produced using an A0 plotter, at key stages in the process. These huge 5x1m plots allow the full survey to be viewed in detail as a single entity, something not possible on the computer screen, and have been the basis of many public lectures and utilised in an ALSF supported exhibition on the Archaeology of the Sands and Gravels of Heslerton, in Malton Museum from 2003-5 (Powlesland 2003b).

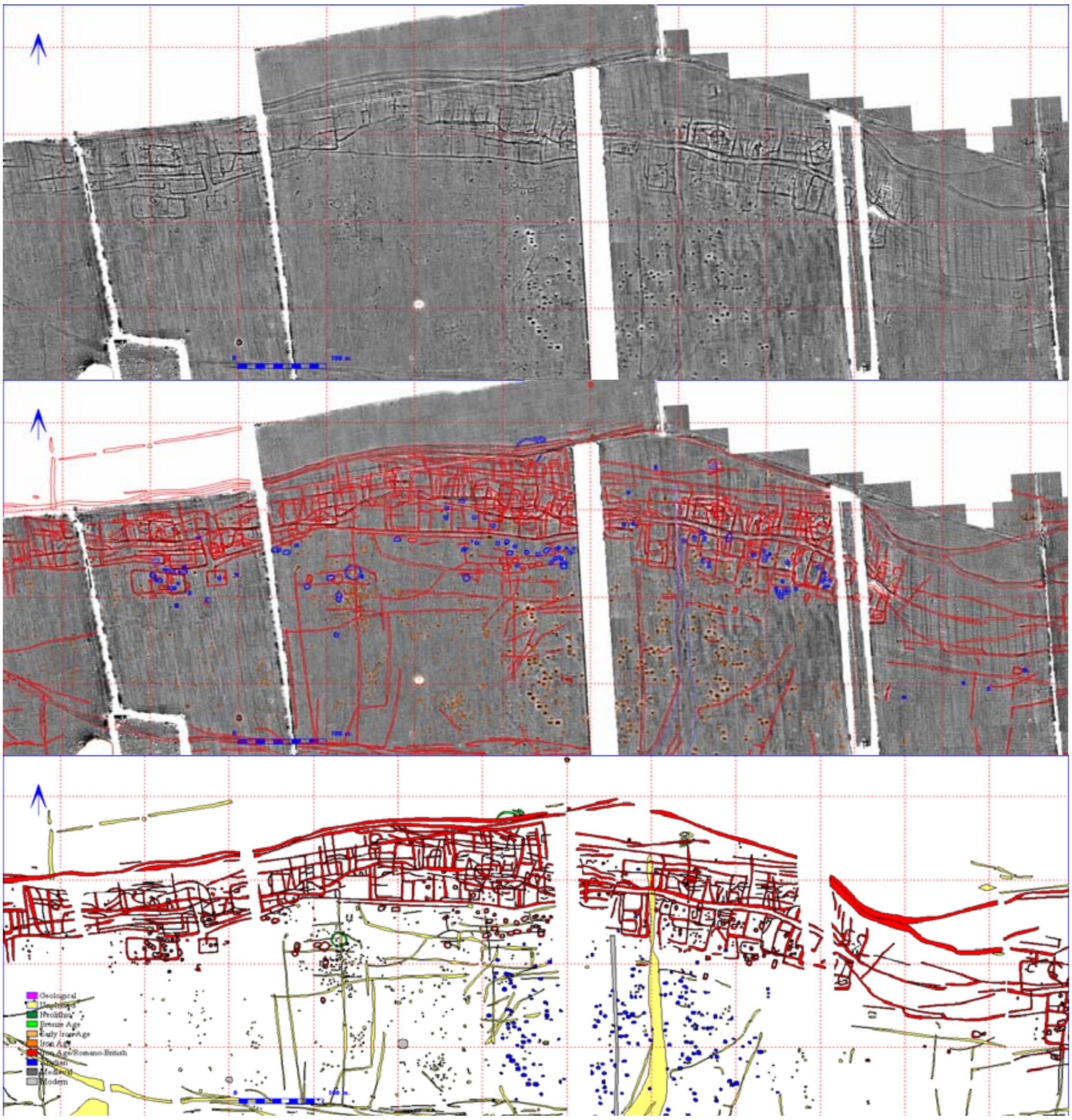

Figure 6. A section of the 'ladder settlement' shown through the geophysical results (top), overlain with the digitised polygon plot (centre), and classified according to basic phase (bottom)

Seeing beneath the plough-soil, sub-surface mapping the buried resource

The auger survey was undertaken with a simple objective, to map the depth to the buried archaeological resource, documenting and mapping the archaeological and natural land surface, the base and top of any blown sands and the thickness of the modern plough-soil. Samples were taken on an arbitrary grid paced out at approximately 50 metre intervals in each field (Figure 7). The grid interval was varied occasionally depending on deposits encountered, prior knowledge of subterranean features such as palaeochannels, and ground conditions. The wind blown sands that overly the archaeological and natural deposits tend to be thicker at the field boundaries, where they have accumulated in hedges over many years and where ploughing has had a lesser effect on their survival. While the field-by-field grid method employed resulted in very close proximity samples along the edges of adjacent fields, this was necessary in order to model the fields accurately as a landscape wide grid would not have enabled the modelling of the field edges.

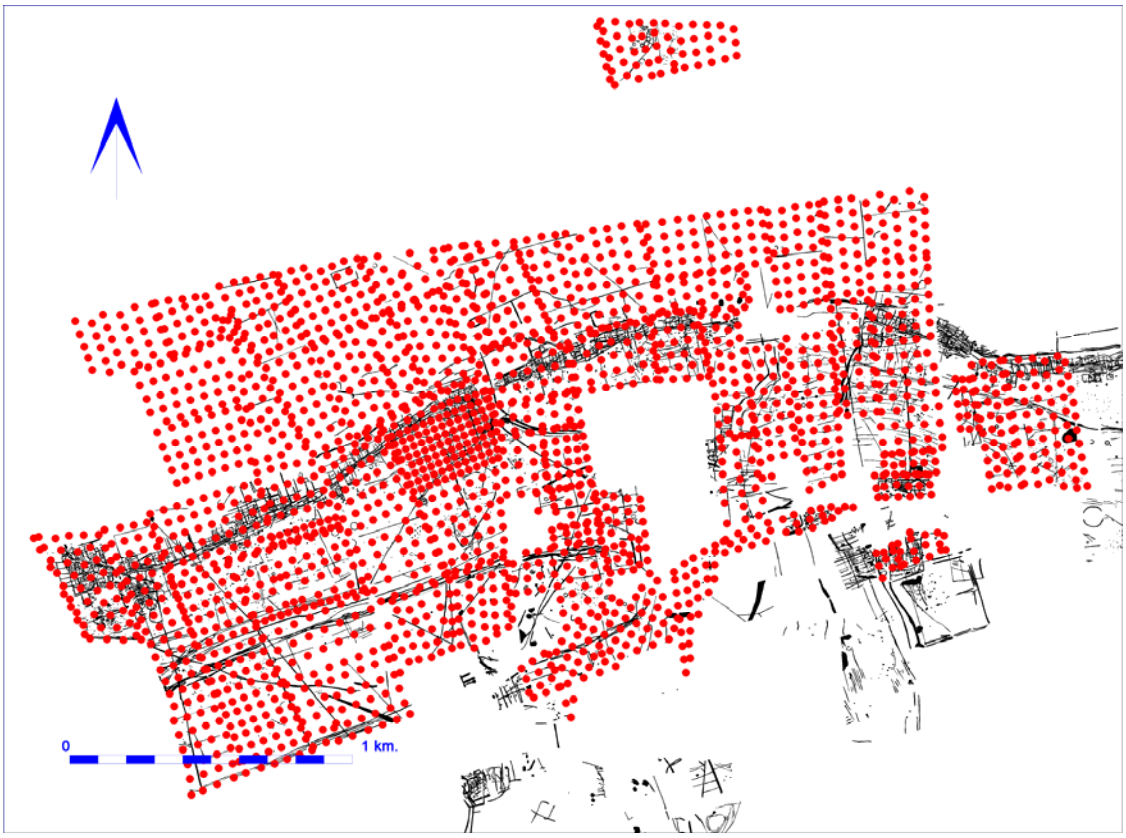

Figure 7. Distribution of auger locations within the project area in relation to the geophysical plot.

As with the geophysical survey, the availability of fields for the auger survey was dependant on access to land that was actively being farmed; the auger sampling coverage is slightly different to the geophysical coverage partially as a result of access restrictions, a slightly shorter time scale than for the gradiometer survey, and the deliberate decision to auger some areas where the geophysical response was poor and leave out others where augering was found to be less effective.

The location of each auger point was surveyed using a Leica System 500 GPS. This gives easting, northing and height data at centimetre precision for the topsoil at each sample point this was then used during data processing to calculate the easting, northing and height for the surface of every deposit encountered in each auger sample.

The deposits evident in each auger sample were recorded on an individual context basis in the field. Attributes such as soil type, colour, texture, and depth below ground level were recorded for each context in a 'Smartlist' relational database operating on a Handspring Palm OS handheld computer. The information stored on the Palm OS machine was synchronised with a Microsoft Access database operating on a desktop PC on the completion of the auger survey in each field. The Access database shared the same structure as the 'Smartlist' database, and housed the cumulative records for all the samples taken. The context recording followed standard LRC procedures and terminology, with the addition of a number of fields to accommodate the description of peat deposits.

The auger survey was generally undertaken blind, i.e. without prior reference to the results of the geophysical survey, as it was considered that this would bias the interpretation of the deposits. On occasions the recording and interpretation of the augers in the field proved difficult. The main problems experienced being (1) when a succession of similar deposits were encountered with gradual or diffuse interfaces, or (2) when depths of wind blown sands were generally consistent across a field, but one or two augers demonstrated much greater depths that could not be explained. Once the context information had been transferred to the database the data were evaluated in order to check for any inconsistencies in the data. This was achieved by a visual examination of the records and by generating preliminary models of the deposits.

Where similar deposits were encountered, such as plough-soil appearing to be much deeper than usual, it has been assumed that an archaeological feature had been encountered with a similar fill to the overlying plough-soil. In such cases a new context has been introduced during the post-survey phase of work and the depth of plough-soil altered to reflect that of the surrounding augers.

In the case of much greater depths of wind blown sand than would be expected, the depths of such deposits have been plotted over the geophysical survey results. Where deep wind blown sands coincided with features apparent in the geophysics it has been assumed that an archaeological feature filled with wind blown sands had been encountered. Although lack of coincidence with known archaeological features did not necessarily mean that archaeology had not been encountered, where this occurred it could not be suggested with confidence that this was the case. In these instances the data has been left unaltered. In all cases the initial raw data has been left unmodified, and it is only the classification of a deposit and the combined depth of overburden that have been adjusted.

The confidence with which deposits have been interpreted is a key issue to the auger survey. The identification of archaeological deposits, whether buried soils or the fills of cut features, proved difficult in the field as little comprehension of the stratigraphy could be gleaned from a 30mm wide sample. As many features will probably be filled with wind blown sand, it is likely that these will have gone unrecognised during the auger survey. A plot of the points at which deposits were noted during fieldwork as either potential archaeology or buried soils, however, demonstrates a strong correlation with the archaeological elements known from the geophysical survey and generally follows the line of the ladder settlement (Figure 8). Given this correlation, it is possible to be a little more confident that the classification of deposits as archaeology or buried soils are correct. The majority of points to the south of the ladder settlement in Figure 8 were noted as buried soil, though this term was later abandoned as it proved impossible to distinguish in an auger sample whether a true buried soil or simply a shallow archaeological feature had been encountered. Those points that do not correlate with the geophysical data and are positioned close to field boundaries can probably be explained as the result of animal activity, which is inevitably concentrated at the field edges.

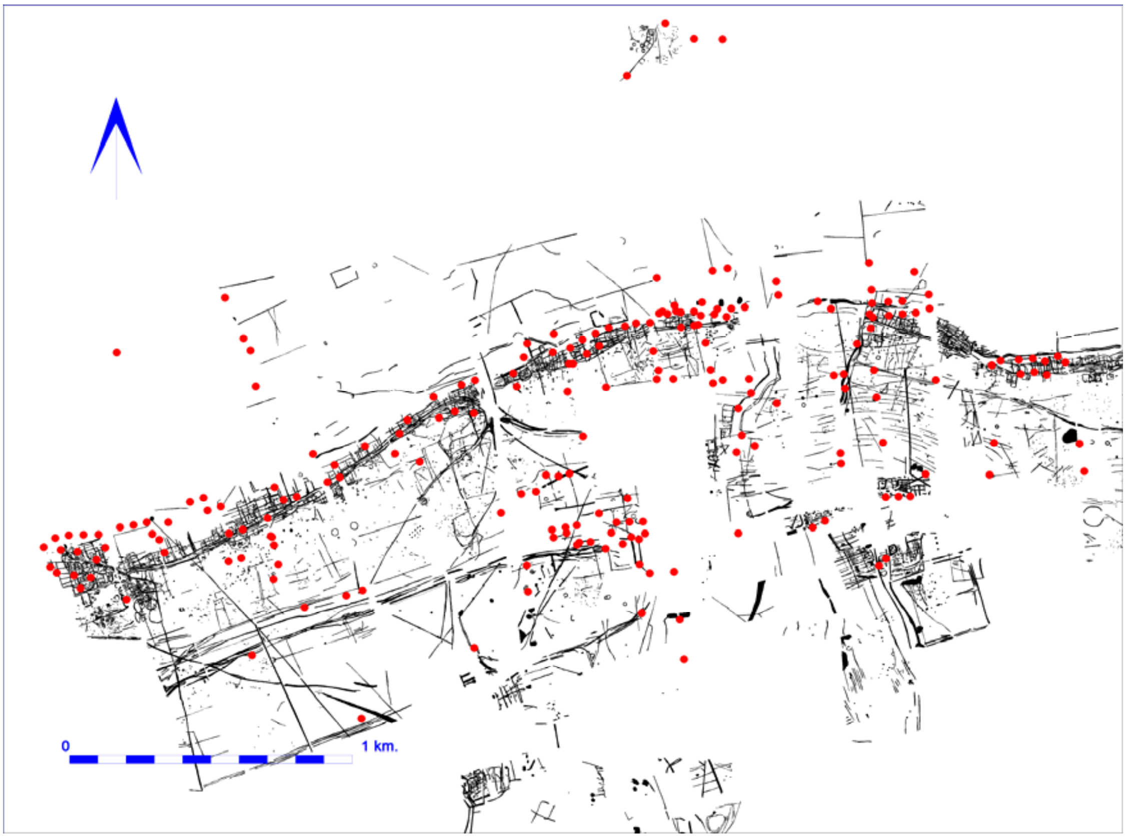

Figure 8. Distribution of auger samples where deposits were classified as archaeology or buried soils over plot of geophysics data. It should be noted that slight discrepancies between the positional data associated with the auger locations and the geophysical anomalies will occur due to the different survey methods employed.

The interpretation of wind blown sands also proved contentious on occasions, as subtle (and occasionally quite dramatic) variations were encountered in the texture and colour of the deposits, the two criteria used in the field to apply this classification. Figure 9 illustrates the plot of auger locations where deposits classified as wind blown sands were encountered. The majority of such deposits are clearly confined to the area over and to the south of the ladder settlement. Those to the north not in close proximity to field boundaries may well have been misidentified during fieldwork or that there were isolated smaller patches of blown sand in the floodplain. The general distribution and comparison with the results from a number of the observation trenches indicate that these deposits have been identified with reasonable confidence.

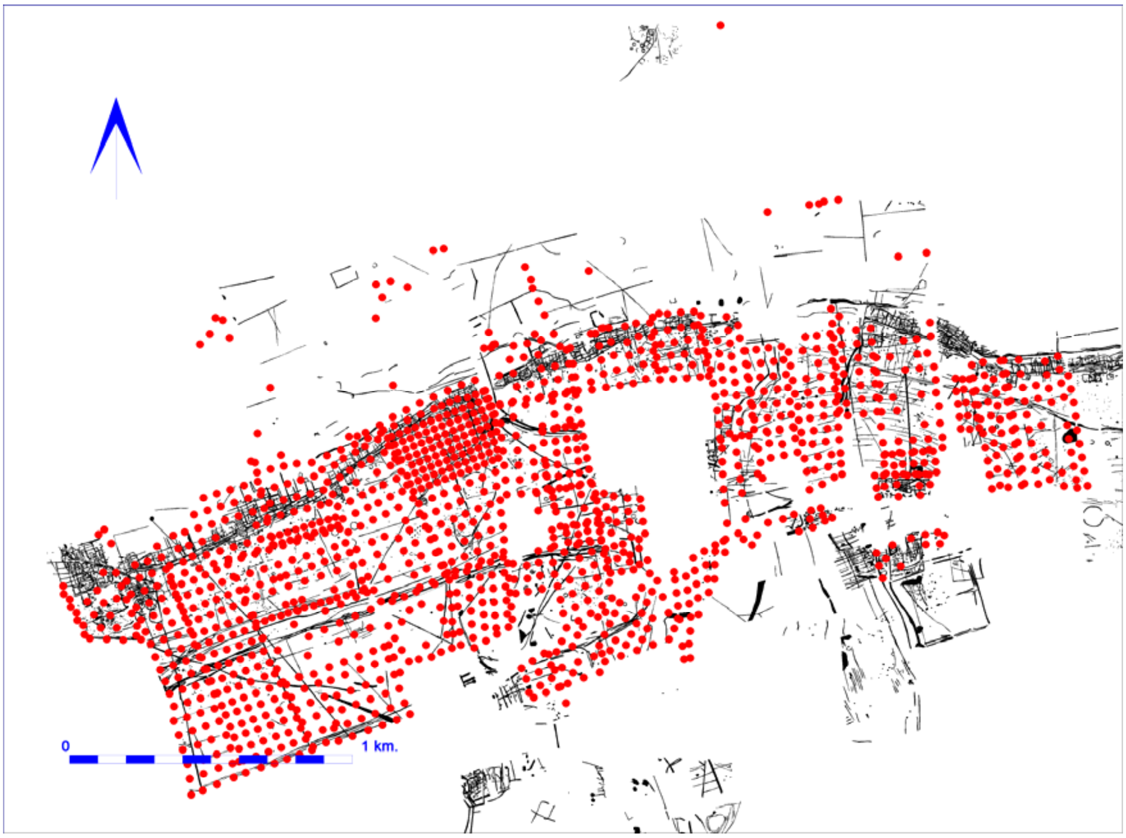

Figure 9. Distribution of auger points where deposits classified as wind blown sands were encountered.

Sub-surface modelling: data processing

The survey data gathered for the auger positions were initially processed using Leica's SKI Pro software, where local transformations were applied to bring the GPS data into the Ordnance Survey co-ordinate system. The information was then exported from SKI Pro as a text delimited file and the data subsequently imported into the database holding the auger information.

A number of update queries were then applied to the data, transferring the easting and northing of each deposit to the relevant fields in the context details table, and calculating the Ordnance Datum height of each deposit. In order to maintain the data structure previously used by the LRC, the data were also converted from metres to centimetres during this process.

The overburden depth was calculated for each auger, and comprises the combined depth of plough-soil and wind blown sands overlying any deposit that may be potential archaeology or natural. It is therefore a conservative estimate of the depth of material protecting the archaeological horizons. A database query was created to calculate the Ordnance Datum height of the base of overburden, and this information was used in the creation of multi-surface models supported G-Sys.

Once the data had been evaluated and corrected, easting, northing and height data were exported from the database for each deposit classified as plough-soil or natural. This created two comma-separated value (csv) files, one for plough-soil and one for natural, pertaining to each field. For those fields in which detailed topographic survey had been undertaken, the plough-soil csv file was augmented with the topographic data to create a more detailed model.

The plough-soil and natural classifications were the simplest to model, as these occurred in every auger. On rare occasions natural was not recorded, usually due to the deposits being impossible to lift because of waterlogging etc. In these instances the OD height at that auger position was simply omitted, and the surface models calculated excluding the missing point but reflecting neighbouring values. Deposits classified as wind blown sand or archaeology were more difficult to model, as both occurred intermittently throughout the auger samples, and both may occur more than once in the same auger. The nature of these deposits incorporating multiple lenses therefore made the creation of precise three-dimensional solid models impossible, as wind blown sands in one auger could not always be directly correlated with wind blown sands in another. For this reason it was decided that the most appropriate intermediate surface between the plough-soil and natural would be one modelling the base of overburden, i.e. the upper surface of potential archaeology. Where archaeology was not present in an auger, this surface would coincide with that modelling the surface of the natural deposits. The data to create this surface were again exported from the database as csv files.

These csv files were individually imported into G-Sys, where they were interpolated using a Delauney triangulation to create geo-referenced contour plots and Digital Elevation Models (DEMs) for the three surfaces in each field. The three DEM surfaces for plough-soil, base of overburden and natural were created at a resolution of 0.50 metres. These were then combined to create a G-Sys multi-model, capable of on the fly interrogation reporting the depth at which the deposits occurred at any given point.

In addition to the multi-models, which cannot easily be illustrated outside the G-Sys software environment, DEMs were generated for each field and at a landscape level based on the thickness of overburden and wind blown sands in each auger. A common colour ramp was applied to each DEM. The overburden and wind blown sand DEMs were created at a resolution of horizontal resolution of 0.50 metres with elevation data at centimetre precision.

Sub-Surface Modelling: Results

The overburden model illustrated in Figure 10 shows the combined thickness of plough-soil and wind blown sands overlying the natural and potential archaeological deposits within the project area. Thickness of overburden is shaded from red (0.35m or less) through orange, yellow and green (0.36 - 0.99m) to blue (1.00m and above). The figure clearly shows those areas where potential archaeology is threatened or being actively damaged by the plough (red), and also those areas where wind blown sands have accumulated along field boundaries (blue).

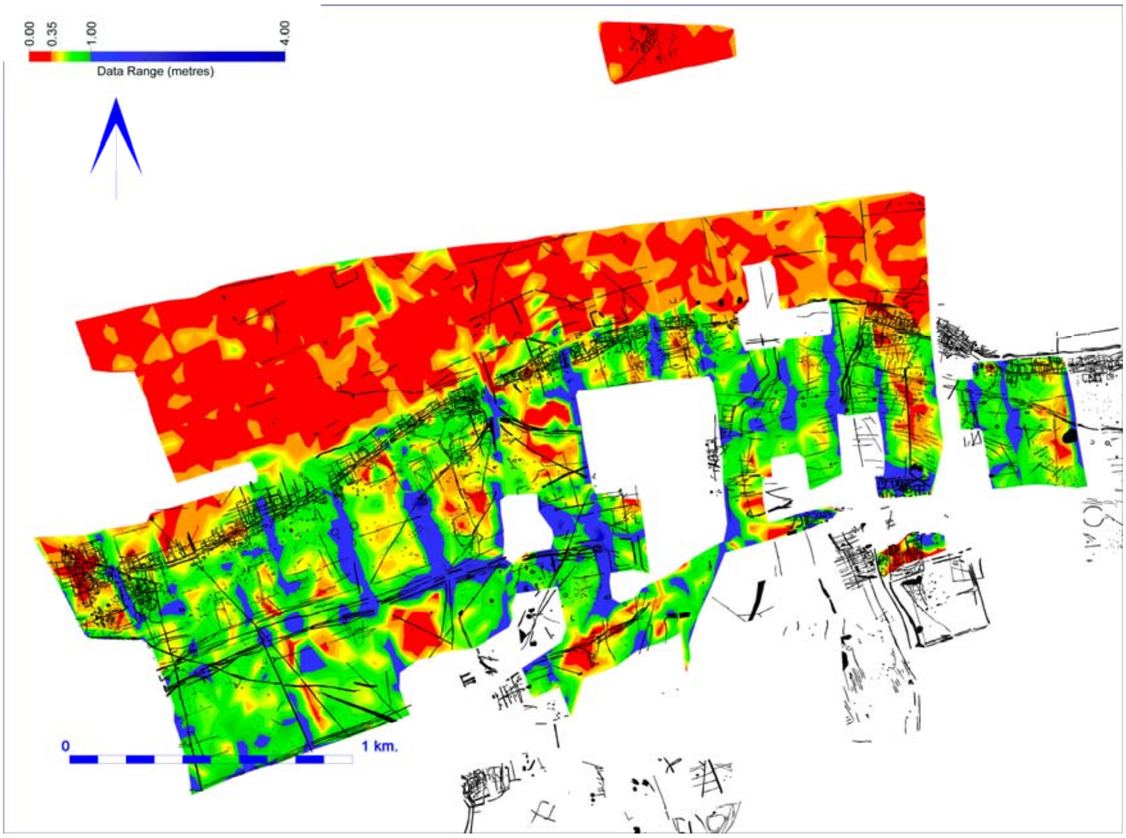

Figure 10. Plot of project-wide overburden model in relation to geophysical results.

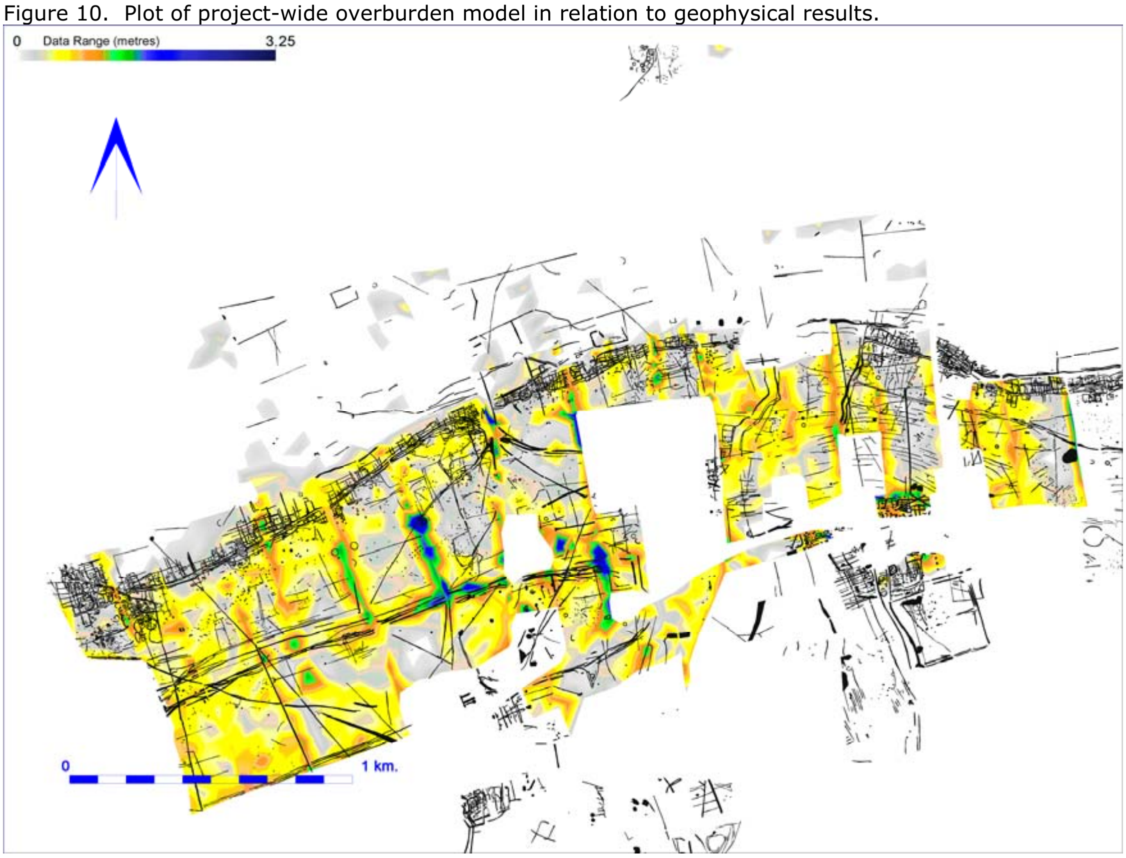

Figure 11. Thickness of wind blown sand deposits in relation to geophysical results.

Figure 11 illustrates the model of the thickness of wind blown sand deposits across the project area. Unlike the overburden model, for which the data were always taken on a conservative basis, the data for the wind blown sand model have been interpreted slightly more leniently. For example, where deposits of wind blown sand have been separated by a thin layer of a different deposit, the combined depth of the wind blown sands has been used, and the lens ignored unless that lens definitely related to an archaeological horizon. The colour ramp applied shows grey (0.01-0.20m), yellow to orange (0.20-1.00m) green (1.00-1.50m) and light blue to dark blue (1.50-3.25m). White areas are either devoid of blown sand deposits or have not yet been surveyed. Areas to the north of the general distribution, shown by isolated patches of grey, are probably exaggerated in the model due to the resolution at which sampling occurred.

Surface collection and assessment of condition through observation trenches

A key element of this project addressed surface sampling problems and attempts to assess feature survival through observation trenches. Gridded collection of surface finds through field-walking is commonly applied in archaeological landscape assessment. There are even those that promote metal detecting (treasure hunting) as a method for landscape assessment seemingly unaware that archaeology is everywhere in lowland Britain and that the removal of essential dating evidence will ultimately compromise our ability to interpret the evidence that has remarkably survived hundreds of years of plough damage. We would argue that when applied to the landscape of Heslerton, both of these approaches are flawed.

The resources required for detailed surface collection are considerable and unless repeated on the same field over a number of years can give a very poor picture of the subsurface archaeology (Hinchliffe and Schadla-Hall 1980). The presence of the blown sands likewise reduces the potential for material to be brought to the surface although lithic material with its smooth surfaces seems to be highly mobile within the soil and appear on the surface in almost every field in Heslerton even those with a considerable cover of blown sand. Repeat visits to one field over a number of years indicate that in the season following a new plough damage event the surface of the field can be literally covered with finds whilst the next ploughing places the material back in the base of the plough-soil where it may remain for many years before it re-emerges at the surface. The theoretical position that metal detectorists only take from the plough-soil is difficult to demonstrate in a landscape where the deepest metal-detector holes encountered, dug at night without the landowner's permission, are nearly a metre deep, cut through .25m of stratified archaeological deposits. The knowledge that there used to be Roman or Anglo-Saxon coins and other dateable materials in this densely occupied landscape does not inform us in any particular way, and any belief that the results of metal detectorists activity are then incorporated in the Portable Antiquities Scheme database are unconvincing, as we have encountered hundreds of detectorists holes throughout the landscape none of which are documented through the Portable Antiquities Scheme.

Rather than devote resources to a field walking programme the LRC have evaluated topsoil sieving as an alternative method of finds recovery from the plough-soil. This method, using regularly spaced, one metre square test pits, which are excavated to the base of the plough-soil and all the soil sieved through a 5mm sieve. The depth of the plough-soil is documented and the finds all weighed and recorded either individually or as groups where appropriate. This approach produces results that can be readily quantified and compared from field to field. Differences in the assemblages not only inform us with regard to what material is contained in the plough-soil but give a clear indication of whether active plough damage is occurring (Figure 12).

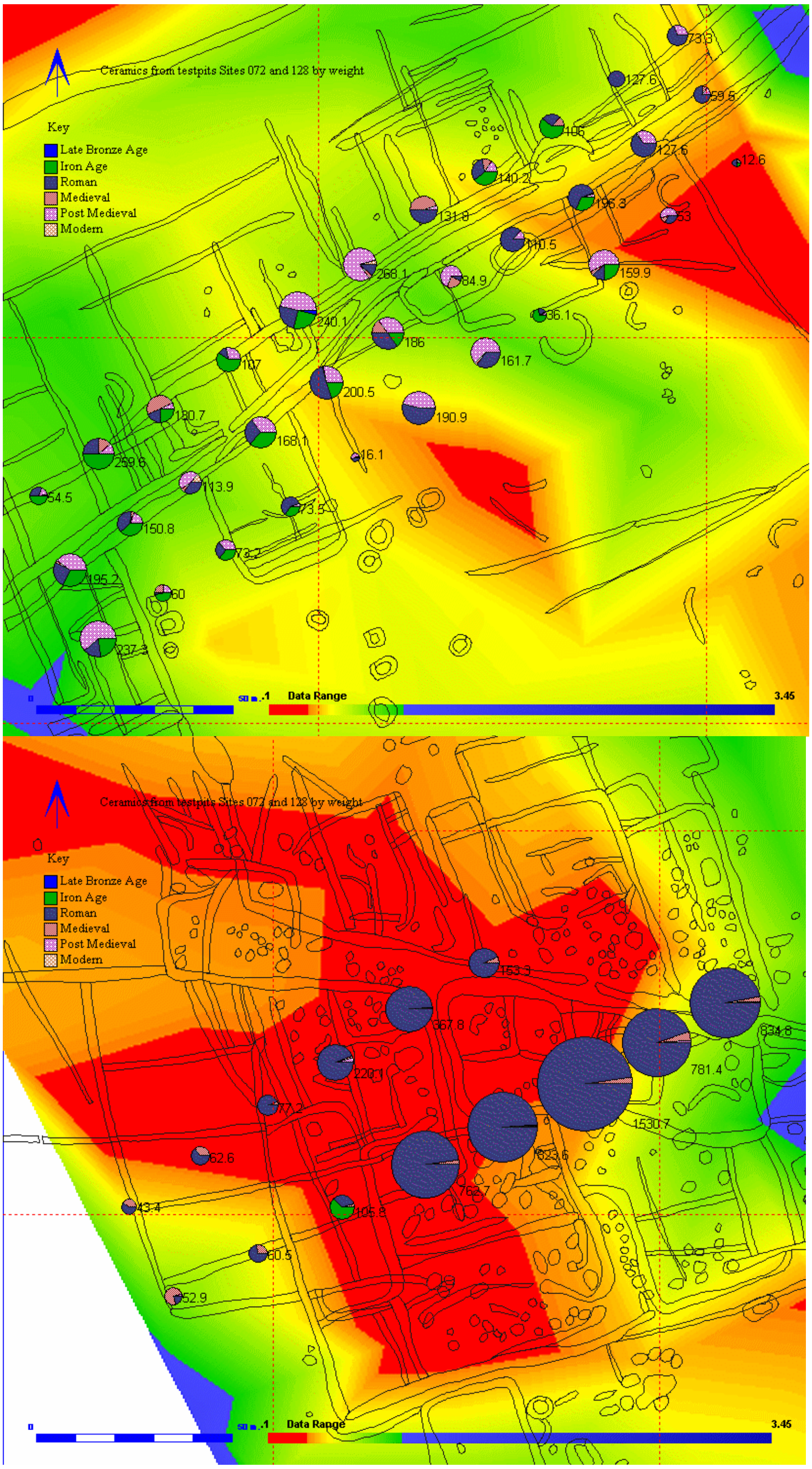

Figure 12. Pie charts reflecting the weight of ceramics recovered from 1m square plough-soil sieving programme across two parts of the ladder settlement. The upper image (Site 072) reflects long term gradual introduction of material into the plough-soil whilst the lower, where the maximum weight of pottery from a single test pit was over 1.5kg, reflects plough damage from the preceding year. The colour model in the background reflects the depth of overburden which is overlain by a plot of the geophysical anomalies.

It was acknowledged at the outset that there would be virtually no time or resources available to transform our detailed understanding of the emerging map through excavation. In order to verify the results of the geophysical and auger surveys and assess site condition a series of 1.5m observation trenches were cut across a number of areas over the ladder settlement and other problematic features, it had been hoped that material in the tops of features exposed during cleaning would help develop the chronological framework relating to the mapped features. The observation trenches were designed to evaluate site condition and particular features identified in the geophysical survey.

This was very successful in one case where active plough damage of structures and enclosures had recently taken place and the interface between the plough-soil and the archaeological deposits was highly disturbed (Site 128) but elsewhere the results were less informative, the resource was simply insufficient to allow anything beyond basic cleaning and plotting of the features and the finds recovered, a problem exacerbated by the very dry conditions. We remain indebted to Dr Nicky Milner assisted by a small group of students from Newcastle University without whose assistance this aspect of the fieldwork would have been less successful.

Mapping the evidence

The features within the observation trenches have each been carefully digitised from high resolution pots of the georeferenced geophysical survey images. The fieldwork exposed serious problems in mapping the resource, arising from the high precision of the GPS equipment and considerable errors in the underlying Ordnance Survey (OS) map projection which is also used in the GetMapping.com air photographic mosaic used by the LRC as the primary base map. The GetMapping.com data (utilised under academic licensing arrangements) is a far more useful resource than OS data either digitally or on paper. However localised variation in the OS projection in Heslerton incorporates errors, as much as 4-5 metres, in both the Eastings and Northings. The georeferencing of the gradiometer surveys, which already incorporate a shift arising from the depth of the features and the location of Heslerton within the global magnetic-field, has always been based on the OS map projection, grid locations being surveyed in using conventional mapping techniques employing measurement from known features or boundaries. Loading the plotted coordinates of features back into the GPS and using the GPS to locate and position small trenches, to expose the features within very large fields, proved to be useless. The degree of variance between the centimetre precise GPS coordinates and local map projection is neither uniform nor consistent and it is clear that in the future the entire dataset may have to be warped and re-projected to fit the boundaries as recorded using the GPS. This problem is not unique to the landscape of the Vale of Pickering, and new projects of this type will need to examine the relationship between the available map base and GPS generated co-ordinates at an early stage if high precision GPS survey is to be combined with data georeferenced to the basic paper map base.

Multi-sensor remote sensing: combining and comparing the evidence

It would be easy to look at the geophysical plot with its dense array of archaeological anomalies and assume that this gives a 'complete' picture of the buried archaeology; it does not. We have been aware since the instigation of the first large scale survey that some features clearly visible in the crop-mark record do not show as magnetic anomalies. Moreover, in the case of Heslerton we are fortunate to have multi-spectral survey (MSS) imagery in addition to the conventional datasets. During 2005 a second NERC award comprising multi-spectral, high resolution vertical digital air photography and Lidar data was granted and although work on this data is progressing and it is too early to report on the analysis of the MSS data here, the vertical high resolution air photography and Lidar data are discussed below.

Multi-spectral imaging with the Daedalus 1268 Airborne Thematic Mapper (ATM) June 1992 multi-spectral flight

The Daedalus 1268 ATM collects radiation from the Earth's surface in 11 different bandwidths, in the visible, near infrared and thermal bands of the electro-magnetic spectrum (Table 1). It is a passive remote sensing device, and is designed for use on an airborne platform. It operates by using a rotating scan mirror to capture the radiated light, with both visible and near infrared being split and then imaged onto a number of silicon detectors. The middle infrared or thermal radiation is dealt with slightly differently, as this is split and then recorded onto three single detector elements, which are enclosed within liquid nitrogen cooled containers.

Band	Lower wavelength	Upper wavelength	Spectral component
One	0.42	0.45	Blue
Two	0.45	0.52	Blue-green
Three	0.52	0.605	Green
Four	0.605	0.625	Red
Five	0.63	0.69	Red
Six	0.695	0.75	Near Infra-red
Seven	0.76	0.9	Near Infra-red
Eight	0.91	1.05	Near Infra-red
Nine	1.55	1.75	Short wave Infra-red
Ten	2.08	2.35	Short wave Infra-red
Eleven	8.5	13	Mid Infra-red or thermal
Twelve	8.5	13	Mid Infra-red or thermal (Half the gain setting of 11)

Table 1. indicating the upper and lower wavelengths of the EMS collected by the Daedalus 1268, in um.

Bands one to five collect data in the visible part of the spectrum, with bands six to eight in the near infrared, bands nine and ten in the short-wave infrared, and bands eleven and twelve in the same thermal wavelength, but with channel 12 collected using half the gain setting, thus utilising a different radiometric sensitivity to help alleviate any potential over-exposure problems.

The scan mirror can be set to three different synchronised speeds (12.5, 25 and 50 Hz), so that data collection at different altitudes can be linked to ground coverage. In order to avoid any gaps in the area coverage along the flight lines, around a 10% overlap between alternate scan-lines is employed. The ground resolution of multi-spectral data is both altitude and airspeed dependent. The data were collected at an altitude of 800 metres, which provides a nominal ground resolution of just under 2 metres per pixel.

The multi-spectral imagery used in this article was collected in 1992, which was before a series of improvements to the scanner that make processing the data much easier (see http://arsf.nerc.ac.uk/instruments/atm.asp for further details).

High resolution colour photographs

The colour near vertical photographs were acquired at the same time as the multi-spectral data, using a Wild RC-10, which provides high resolution photographs, with a negative format of 230mm by 230mm. During the 2005 survey, the option of using a Rollei medium format digital camera was been offered by NERC and selected in preference as digital imaging systems offer better latitude than film and the data supplied in digital form ready for incorporation in the landscape dataset. The digital camera has a CCD resolution of 4080 by 4080 (16.64 megapixels with 48 bits per pixel generating 96Mb files), the actual spatial resolution of the images provided depends on the altitude of the aircraft during the acquisition phase, which in our case was 800 metres, giving a nominal ground resolution of around 14cm per pixel.

During 2005, thanks to the generosity of a local pilot Ray Rochester, it was possible to fly the area in a light aircraft in the same week as the NERC survey was undertaken. A number of fields form our reference fields where crop-marks form on a regular basis and are visited each time the area is flown to check on crop-mark conditions. In two cases a field named 'Roundhills', Heslerton Site 005, which contains parts of a square barrow cemetery, and Heslerton Site 020, which contains a major trackway and associated features linking the 'ladder settlement' on the ancient fen edge with the chalk downlands on the top of the Yorkshire Wolds, the results from the NERC air photography show clear crop-marks, but when viewed obliquely from all sides these features either did not show particularly clearly. In the case of Site 020 the trackway can be traced in a second field Site 052 where the crop-marks were clearly visible in the riper crop when viewed obliquely (Figures 13 and 14). It appears that the potential for the identification of crop-mark evidence in vertical photography, particularly during the green ripening stage, is greater than that from oblique images taken using a handheld Single Lens Reflex (SLR) camera. It is possible that the response is different when the crop is viewed vertically as a result of differences in the lower parts of the crop vegetation which can be seen vertically, whereas when seen obliquely one is primarily viewing differences at the top of the canopy.

The potential for the identification of crop-marks in high resolution vertical photography is admirably demonstrated using Google Earth (www.earth.google.com) software designed for delivery of high resolution satellite and air-photographic imagery for the whole of the globe. At the time of writing parts of England include coverage comprising 12.5 cm resolution air photography, which whilst not taken with a view for crop-mark identification do contain hundreds of crop-marks.

Figure 13. High resolution vertical digital photograph showing crop-marks on Sites 020 and 052. (Source NERC)

Figure 14. Oblique air photograph covering parts of Site 020 and Site 052, taken a few days before the vertical image Figure 13 above. The features in Site 052 show clearly in both images the details in Site 020 are however barely visible in this image.

Case study areas

In order to demonstrate the complimentary returns from three different passive forms of remote sensing; aerial photography, multi-spectral imagery and magnetometry, two case study areas with different underlying geologies were chosen for detailed analysis (Figure 15). The first was situated in an area of alluvial sands and gravels in the floodplain of the River Derwent, with areas of desiccating peat, and was located over a known Iron Age Square Barrow cemetery. The second was on the alkaline sands and gravels in the blown-sand zone, and was known to contain parts of the Late Iron Age/Romano-British 'ladder settlement' and an early Anglo-Saxon or Anglian settlement. The choice of these two locations would allow us to compare and contrast the different returns from each type of remote sensing, with particular interest in the difference in return over the two different geologies.

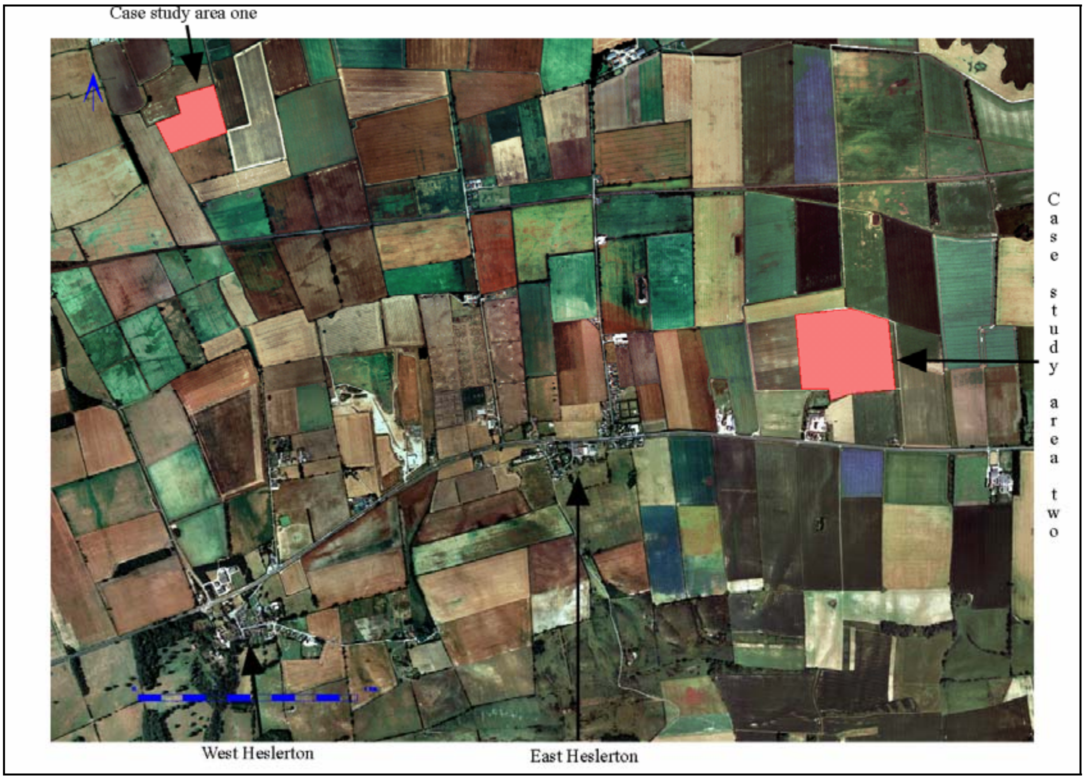

Figure 15. Location of the two study multi-sensor case study areas. Air Photographic base map from Getmapping.com.

Case study area 1

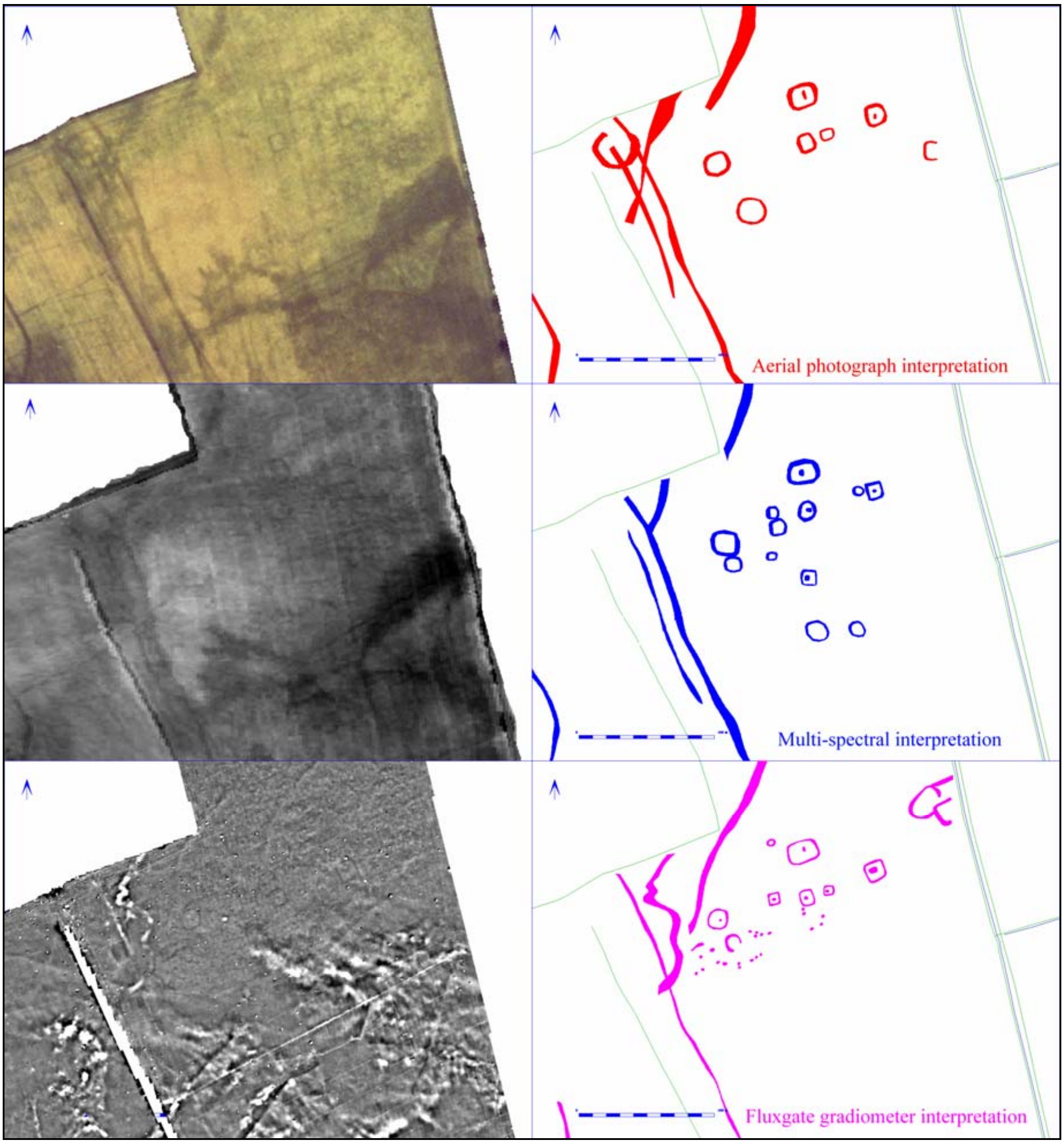

Figure 16. Shows the case study area one, with a colour rectified oblique aerial photograph above, Band 11 (thermal) of the June 1992 multi-spectral image in the centre and the fluxgate gradiometery survey below (scale bar 100 metres).

Case study area 1 is shown in Figure 16 above, the interpretative drawings on the right are of archaeological features only, with geological features and field drains removed. This square barrow cemetery was previously known from aerial photographs, and occupies a low sandy knoll, seen in the aerial photograph as a lighter zone near the centre of the area. A quick glance reveals that the three remote sensing techniques all find the main five barrows, but also shows that each technique can be used to finds features which are not detected by the other methods.

The different returns are visually displayed in Figure 17, where those anomalies uniquely occurring in one form of remote sensing only have been colour coded, with the anomalies detected by more than one of the techniques indicated in black. The multi-spectral data detected more barrows to the south of the main cemetery area, where both crop-mark formation and magnetic contrasts are very subtle. The gradiometer was the most likely to find the central grave pits of the barrows. The gradiometer also detected a number of localised anomalies on the sandy knoll, which may prove to be flat inhumation graves next to the more prominent barrows.

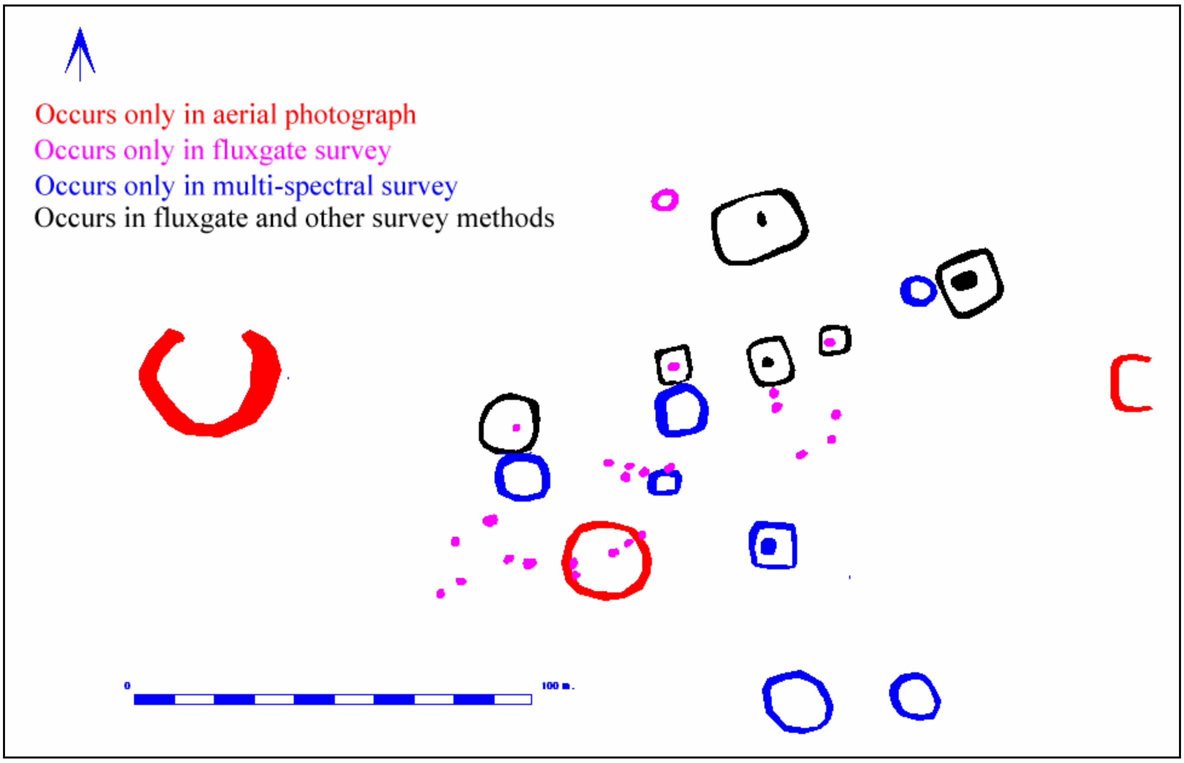

Figure 17. Showing the returns from three different forms of remote sensing

The aerial photograph shows ay least one large circular crop-mark which may be a late Neolithic or Early Bronzed Age barrow, and thus both predates and provides the focus for the smaller and later round and square barrows in the area.

Case study area two

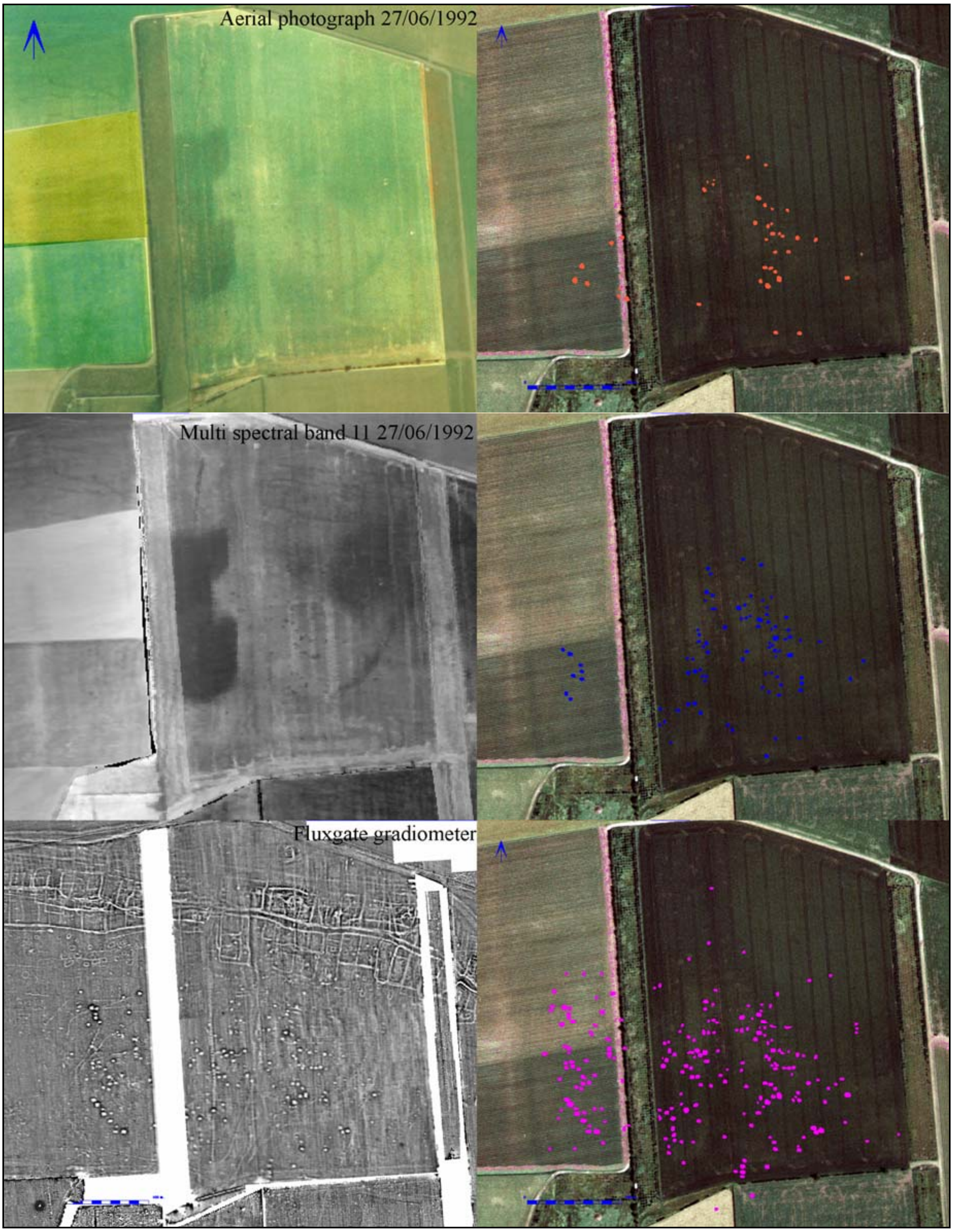

Figure 18. A comparison of three different forms of remote sensing (Site 27), with interpretative plots of *Grubenhäuser* only on the right

The second study area covers an Early Anglo-Saxon or Anglian settlement, and parts of the 'ladder settlement'. This area was chosen on account of the large number of *Grubenhäuser* revealed in the geophysical survey (Tipper 2004).

The left half of Figure 18 shows a comparison of the three types of remote sensing used, with an interpretative plot of only the *Grubenhäuser* on a background of the Getmapping.com data on the right. It is immediately evident that the returns from each form of remote sensing vary considerably in this area. The crop-marks, which indicate the presence of a ladder settlement in the north of the area, were already well known before the 1992 flight. In the 1992 vertical photographs a less well known group of crop-marks to the south of the ladder settlement exhibiting the typical size and grouping of clusters of *Grubenhäuser*, were identified; it was this discovery that inspired the geophysical survey in this area. This survey was carried out on different occasions, and has been split into two sites, Site 027 in the east and Site 028 in the west. The area was particularly responsive to the fluxgate gradiometer, and a total of 217 anomalies that were interpreted as *Grubenhäuser* were detected. The total number of anomalies for each remote sensing technique are displayed in table 2.

Type	Site 27	Site 28	Total
Fluxgate	151	66	217
Multi-spectral	79	9	88
Cropmark	29	8	37

Table 2. Numbers of *Grubenhäuser* detected by the different remote sensing techniques

Because this area responded particularly well to the fluxgate gradiometer, the difference in anomaly detection was not so marked in this second case study area, with none of the ladder settlement in the northern part of the field detected by the multi-spectral imagery or the aerial photograph not being present in the gradiometer data. However, in the Anglian settlement to the south, 22 possible *Grubenhäuser* not detected by the gradiometer were present in the multi-spectral data (see table 3 and Figure 19). In all, a total of 173 *Grubenhäuser* were discovered in site 27, of which 67 were detected both by the fluxgate gradiometer and the multi-spectral imagery. This means that if only the gradiometer had been used, then 22 *Grubenhäuser* would have gone undetected, and if only the multi-spectral imagery had been used, then 86 *Grubenhäuser* would remain unknown.

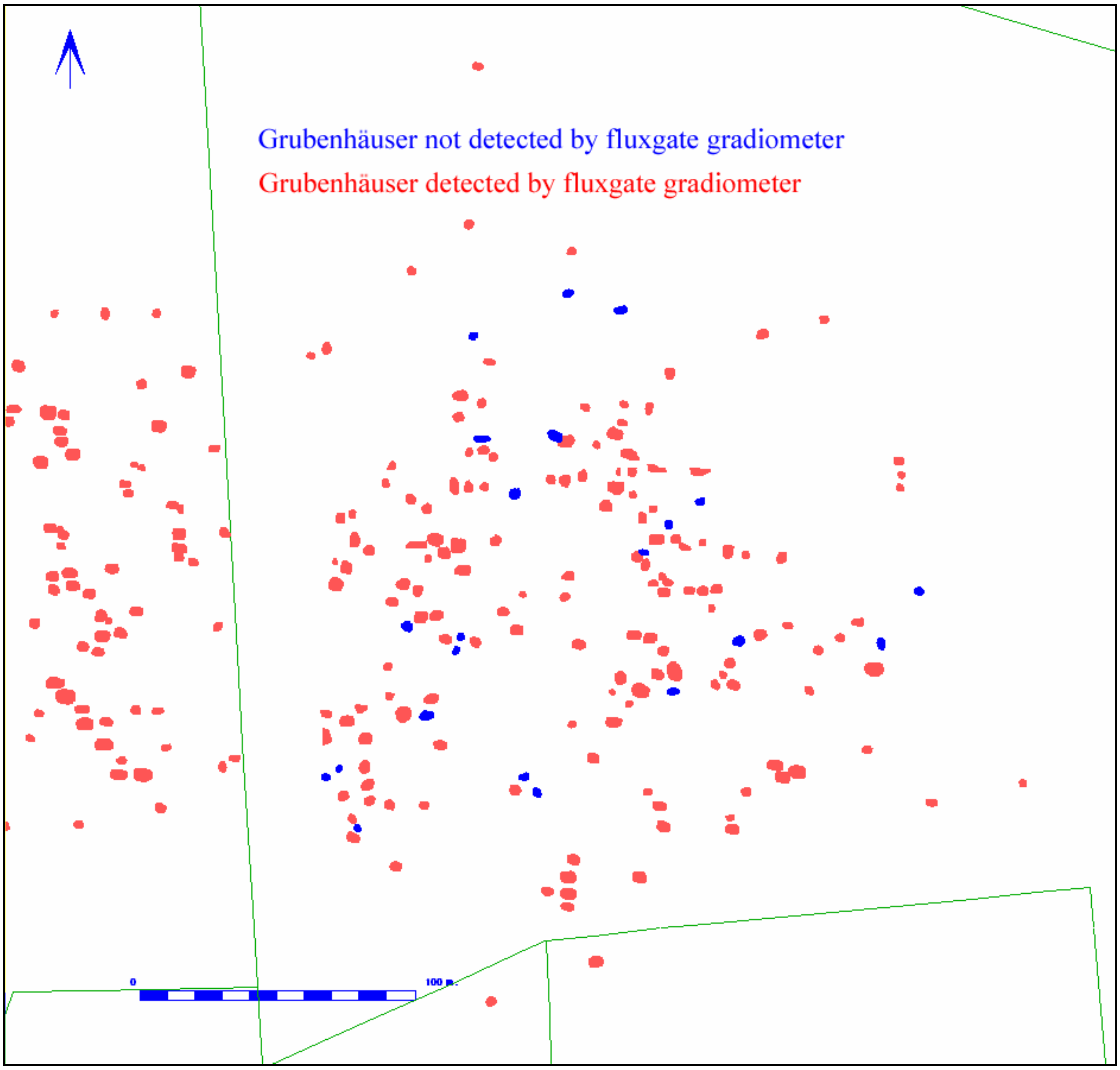

Figure 19. *Grubenhäuser* not detected by the fluxgate gradiometer

	Site 27	Site 28
Fluxgate unique	94	57
Multi unique	22	0
Cropmark unique	0	3
Found by all 3	29	2
Found by fluxgate and multispectral	28	5
Found by fluxgate and cropmark	0	2
Actual Grubenhaus total	173	69

Table 3. Tabulation of the numbers of *Grubenhäuser* identified in each of the three data sources either uniquely or shared across different data sources.

However, these numbers cannot just be added together to give us the total number of *Grubenhäuser* associated with the Anglian settlement, as a number of the same anomalies are present in more than one form of remote sensing. Table 3 has a breakdown of the unique returns from each form, with anomalies occurring in more than one source also tabulated. This demonstrates that a total of 242 different *Grubenhäuser* were detected using the three different types of remote sensing.

Lidar high resolution surface modelling

Lidar is one of the newer sources of remote sensing data applicable to archaeological research. Lidar instruments use the reflection of a high speed scanning laser beam to record easting, northing, elevation and reflected intensity recording both a first and last return of the beam which can penetrate vegetation Although the vertical precision (15cm) of Lidar data does not match that gathered by our Kinematic GPS system (.5cm) the ability to recover elevation data at densities of about 1 per metre square covering a 10x8km area in about an hour far out-performs out survey rates in which it took about a day to cover each field, admittedly at higher collection density rates. Relative height variation within the Lidar data is likely to have a greater precision than specified and work is in progress to compare the two sources to quantify that difference.

The NERC Lidar survey, carried out by the Cambridge University Unit for Landscape Modelling, reveals previously unknown barrows on the northern edge of the Yorkshire Wolds and has revolutionised our understanding of the flood-plain area. Used as the basis for flood modelling it reveals the precision with which the ladder settlement follows the edge of the ancient wetlands and demonstrates that the surface profile of the flood-plain itself must have changed considerably since the late Prehistoric period, as a consequence of removal of surface peat deposits and shrinkage of the buried peat due to drainage. As a digital data source it also provides the basis for draping the landscape dataset on a 3D model which gives further insight into the landscape when viewed from different positions in 3D (Figure 20).

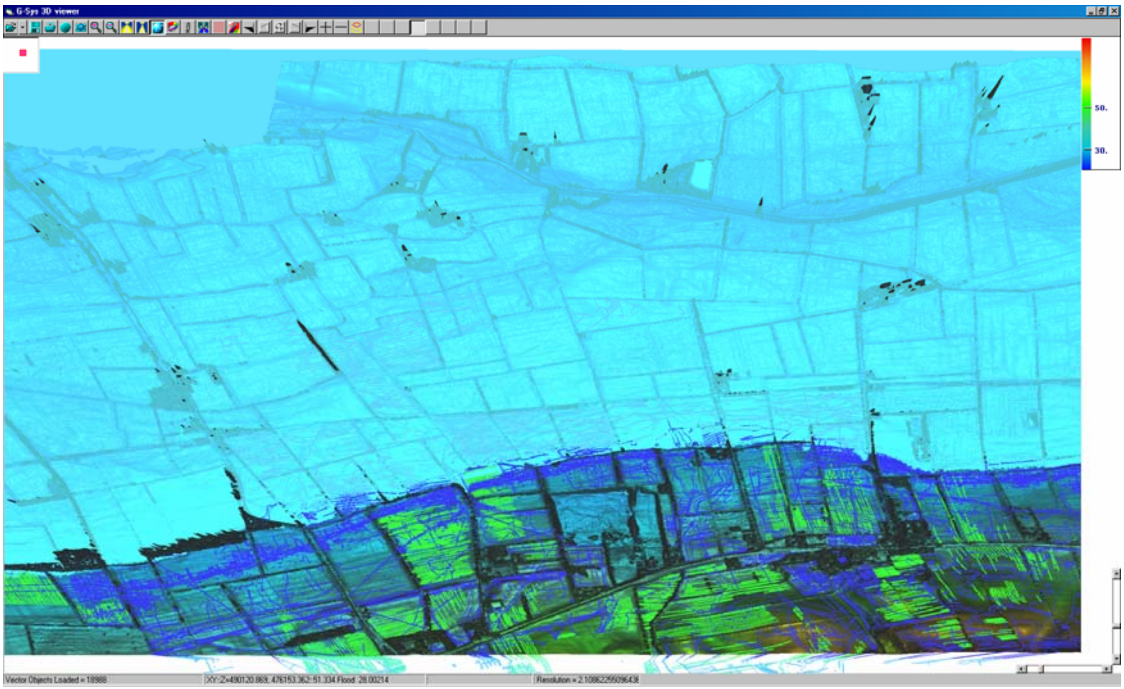

Figure 20. Lidar data overlain with geophysical plots in blue (main features) and green (rig & furrow) with a transparent flood overlay at 28m AOD which is closely followed by the northern limits of the ladder settlement.

Conclusions

Thirty years ago the known archaeology of East and West Heslerton comprised the East Heslerton long barrow, discussed by Canon Greenwell and re-examined by the Vatchers in 1966, a number of round barrows rather poorly described, also by Greenwell, one of which gave its name to a Neolithic pottery type, Heslerton Ware, and the Late Bronze Age palisaded enclosure of Devil's Hill, excavated by TCM Brewster; the rather more famous Staple Howe also excavated by Brewster is situated in the next parish (Greenwell and Rolleston 1887, Mortimer 1905). A fine Late Neolithic/Early Bronze Age jet necklace discovered during aggregate extraction at Cook's Quarry, West Heslerton, in the early 1960's that lay in fragments in Scarborough museum was the only indication of the important archaeology that ran through the area on the edge of the flood-plain of the River Derwent. Following the discovery of a multi-period settlement and cemetery complex during removal of overburden at the same quarry in 1977, a programme of very large scale rescue excavations and landscape survey was begun which have revealed the most detailed picture of an archaeological landscape for its scale in Britain.

During the first few years of excavation it became clear that much of the archaeology of Heslerton was important not simply because it is there, but because large areas of settlement and cemetery evidence for the Neolithic to Early Medieval periods lay sealed beneath deposits of blown sand which preserved evidence such as intact floor deposits not commonly found on rural sites in Britain. A programme of remote sensing initiated during the first season of excavation on an *ad-hoc* basis but later supported by research grants from NERC and English Heritage and most recently through the English Heritage managed ALSF programme have revealed flaws in our appreciation of the archaeological landscape based on isolated 'sites', mostly identified through accidental discovery. A problem particularly associated with buried landscapes is that accidental discovery is the norm, especially in an area where the discovery of plough scars cut into an apparently featureless reddish sand, could be mistaken for undisturbed ground. Landscapes sealed by aeolian or blown sands are particularly difficult to assess since the present land surface gives few clues about what lies beneath.

The work undertaken in Heslerton has been driven by a desire to identify the archaeological resource as a whole, to provide context for the known and excavated areas and gain insight into the evolution of the landscape unconstrained by chronological boundaries. Attention has, until recently, been primarily focussed on the examination of a 1.5km wide strip of land on the sand and chert/chalk gravels extending from the foot of the Yorkshire Wolds to the lower spring line on the edge of the flood-plain of the Vale of Pickering. Work is currently in progress assessing the archaeology of the flood-plain, itself another source of aggregates.

We need to be very aware that with the exception of the hostile locations (by virtue of the high water table or steep slopes of the Wolds), where other potentially important evidence may still lie buried in relict lakes and pools beneath the plough-soil, the blank areas in our remote sensing plots do not represent areas without a past, this was has been strikingly demonstrated at Cook's Quarry in the last four years, where the quarry owner now funds excavation ahead of extraction. A 30m diameter hengiform enclosure of probable Neolithic date with a number of associated cremations was undetected by magnetometry, but had been seen as a poor crop-mark in the 1970's, the multitude of other features including barrows and field systems had not been detected by any method (Figure 21).

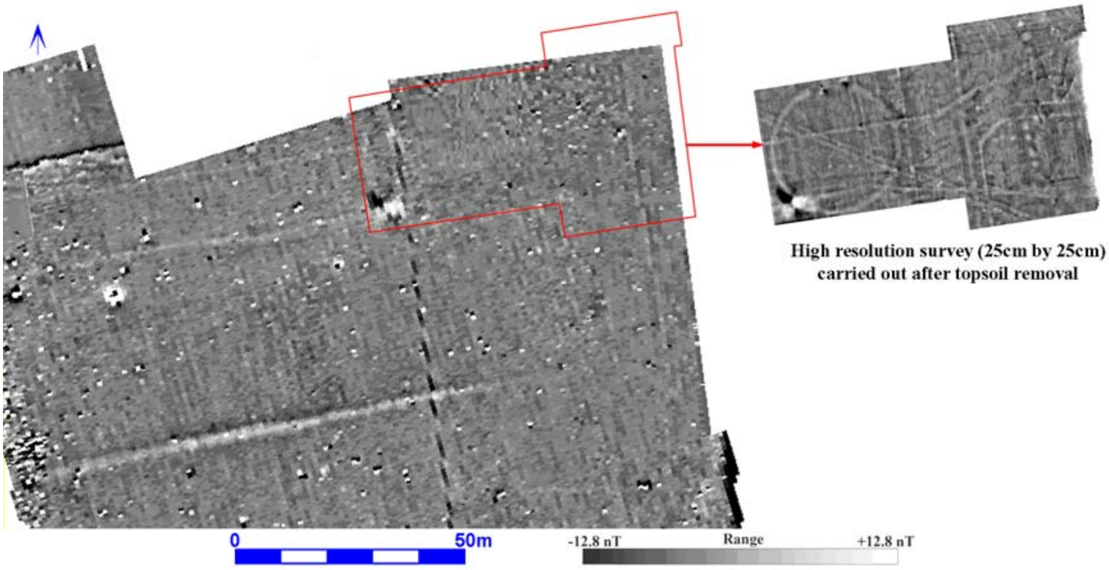

Figure 21. An area of gradiometer survey at Cook's Quarry prior to excavation; of the three linear anomalies only the larger feature is ancient, a prehistoric pit alignment. The high-resolution survey (inset) carried out after topsoil stripping, revealed the full extent of a hengiform enclosure and pit alignment.

To those charged with securing the future of the past, Heslerton must seem like a nightmare, the tip of an archaeological iceberg, with totally unanticipated density of activity covering over 1000 Ha, to others it is a dream. In a landscape which appears from recent pollen studies to have remained cleared and open from the Late Mesolithic period onwards, only those areas too hostile for use by virtue of the high water table or steep slopes of the Wolds show no evidence of past activity. Once large area contiguous geophysical survey was in progress it rapidly became clear that any attempt to develop a management strategy for the resource required much more than an air-photographic and geophysical survey plot. The buried landscape is under threat from large scale aggregate extraction, road schemes and the gradual, and effectively invisible, erosion cased by modern agricultural practices. Given that only a tiny percentage of the mapped remote sensing data has been directly examined, adding chronological depth and the ability to accurately interpret the mapped features, we need not only to identify the distribution of the resource but also to determine its likely condition and potential to add new knowledge.

A singular weakness in the work at Heslerton it is the lack of comparable landscape datasets from other parts of the country, as without them we may end up confusing what is the norm with something, which at present looks unique.

The Landscape dataset for Heslerton still largely amounts to a series of maps which require ground truthing; however the combined evidence does offer us the opportunity of identifying those areas where aggregate extraction would be un-economic on the grounds of excavation cost, those areas where the resource is likely to be best preserved and those areas where a degree of archaeological risk can be calculated based on the evidence to hand, including some where the risk is likely to be minimal.

During the life of the project we have seen great changes in the nature of archaeological funding particularly for projects that are development led, this seems sadly to have been seen as an opportunity to greatly reduce the level of funding for archaeology from central government. Today there is a focus on the management of landscapes and securing sustainability of the archaeological resource. However, you cannot manage what you do not know about, and you cannot sustain a resource without, at lest some level of understanding of the resource, and probably some degree of monitoring and therefore documenting it.

A consequence of the work in Heslerton is that now that we gathered all this evidence we are responsible for its future. If it is to be sustainable then it serves no purpose without interpretation and, with the exception of certain classes of monument, this can only be secured through further work.

A second consequence has been the absolute requirement to work in a highly computerised and integrated environment and develop new layers of narrative documentation both to engage the 'landkeepers' whose land holds this magnificent resource but also to underpin the conventional databases, maps and image banks. With such a large project covering so much land that is in use it is vital that the 'landkeepers' are kept informed, in modern parlance they are the stakeholders, but to us they are so much more: none of them chose to have this archaeology on their land, but they are as interested as the archaeological professional in the fact that it is there.

The project, of course, has only just begun. The challenge now is to work with the aggregates industry, the farmers, landowners and planners to secure a future for a past. A future in which we hope to see the resource sustained through management, examination and interpretation as part of a perpetual landscape park, an archaeological and environmental living laboratory for everyone to enjoy, from 5 year olds to 95 year olds, and from the academic to the simply interested.

The Landscape Research Centre
January 2006

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