Archaeological geophysical prospection
in peatland environments

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2010

Volume 1 of 2

Abstract

Waterlogged sites in peat often preserve organic material, both in the form of artefacts and palaeoenvironmental evidence as a result of the prevailing anaerobic environment. After three decades of excavation and large scale study projects in the UK, the sub-discipline of wetland archaeology is rethinking theoretical approaches to these environments. Wetland sites are generally discovered while they are being damaged or destroyed by human activity. The survival *in situ* of these important sites is also threatened by drainage, agriculture, erosion and climate change as the deposits cease to be anaerobic. Sites are lost without ever being discovered as the nature of the substrate changes. A prospection tool is badly needed to address these wetland areas as conventional prospection methods such as aerial photography, field walking and remote sensing are not able to detect sites under the protective over burden.

This thesis presents research undertaken between 2007 and 2010 at Bournemouth University. It aimed to examine the potential for conventional geophysical survey methods (resistivity, gradiometry, ground penetrating radar and frequency domain electromagnetic) as site prospection and landscape investigation tools in peatland environments. It examines previous attempts to prospect peatland sites, both in archaeology and environmental science. These attempts show that under the right circumstances, archaeological and landscape features could be detected by these methods, but that the reasons why techniques often fail are not well understood.

Eight case-study sites were surveyed using a combination of conventional techniques. At three of the sites ground truthing work in the form of excavations, bulk sampling and coring was undertaken to validate the survey interpretations. This was followed up by laboratory analysis of the physical and chemical properties of the peat and mineral soils encountered. The key conclusion of the case study work undertaken is that conventional geophysical prospection tools are capable of detecting archaeological features in peatland environments, but that the nature of the deposits encountered creates challenges in interpretation. Too few previous surveys have been adequately ground truthed to allow inferences and cross comparisons. The upland case studies demonstrated that geophysical survey on shallow types of upland peat using conventional techniques yields useful information about prehistoric landscapes. The situation in the lowlands is more complex. In shallow peat without minerogenic layers, timber detection is possible. There are indications that in saturated peat the chemistry of the peat and pore water causes responses in the geophysical surveys, which could be developed as a proxy means to detect or monitor archaeological remains. On sites where the sediments are more complex or affected by desiccation, timbers were not detected with the methods attempted. However, important landscape features were and there are indications that geophysical surveys could be used as part of management and conservation strategies.

This thesis concludes that geophysical prospection contributes to theoretically informed wetland archaeology as a tool for site detection, landscape interpretation, and conservation. Future research should aim to further our understanding of the relationship between geophysical response and peatland geochemistry, alongside a more extensive programme of surveys and ground-truthing work to improve survey methodologies and archaeological interpretations.

Acknowledgements

Declaration of publications

The following article has been published related to this thesis:

Darvill, T, Wainwright, G, Armstrong, K, & Ixer, R, 2009, Strumble-Preseli ancient communities and environment study (SPACES): Sixth report 2007–08. Archaeology in Wales, 48, 47–56.

Case-study reports were produced during the course of the project to maintain reporting obligations to English Heritage, local HERs and landowners:

Armstrong, K & Cheetham, P, 2008a, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Survey at Flag Fen. Area One pilot project, September 2007, Radar and Resistance Tomography Supplemental Report*: Unpublished limited circulation report. Copy accessed at: Bournemouth University & Fenland Archaeological Trust

Armstrong, K & Cheetham, P, 2008c, *Archaeological Geophysical Survey in Peatland Environments: Case Study Survey of the Sweet Track in the Somerset Levels. Surveys Near Canada Farm and The Old Peat Works, November to December 2007, Preliminary Report*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, English Heritage and Somerset HER

Armstrong, K & Cheetham, P, 2008e. *Archaeological Geophysical Prospection in Peatland environments: Case study survey at Flag Fen Area One pilot project, September 2007.* Unpublished limited circulation report. Copy accessed at Bournemouth University and Fenland Archaeological Trust

Armstrong, K, 2009, *Interim Reporting on Ground Truthing Excavations at Yellowmead Down, Sheepstor (Devon), October 2008*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park HER & English Heritage

Armstrong, K & Cheetham, P, 2009a, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Surveys at Drizzlecombe Stone Row Complex, Dartmoor, Devon* Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park HER, English Heritage

Armstrong, K & Cheetham, P, 2009b, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Surveys at Yellowmead Multiple Stone Circles and an adjacent Cairn, Yellowmead Down, Sheepstor, Dartmoor*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park Authority HER, English Heritage

Armstrong, K & Cheetham, P, 2009c, *Archaeological Geophysical Survey in Peatland Environments: Case Study Survey at Flag Fen, (Area 2), Peterborough, Cambridgeshire*: Unpublished limited circulation report. Copy accessed at: Bournemouth University & Fenland Archaeological Trust
Order changed to run in date of publication, not date of fieldwork

 The research has also been disseminated at conferences, as oral papers and posters:

Armstrong, K, 2008. Archaeological Prospection in Peatland Environments: thinking in 3D Presented at: *Computer Applications in Archaeology UK Chapter Meeting. February 1-2, 2008,* University of York.

Armstrong, K & Cheetham, P, 2008b. Archaeological Geophysical Prospection in Peatland Environments: Locating the Sweet Track at Canada Farm, Shapwick Heath (Somerset) Presented at: *Recent Work in Archaeological Geophysics. December 2008,* The Geological Society, Burlington House, London.

Armstrong, K & Cheetham, P, 2008d. Locating the Sweet Track: Trialling Archaeological Geophysical Prospection in Peatland Environments. Presented at: *EIGG Postgraduate Symposium. August 2008,* British Geological Survey, Keyworth, Nottingham.

Armstrong, K, Darvill, T & Cheetham, P, 2009. Archaeological geophysical prospection in peatland environments: case studies and suggestions for future practice Presented at: *Memoire du sol, espace des hommes; the 8th International conference on Archaeological Prospection. September 9-12, 2009,* Arts et Metiers, Paris.

The work at Yellowmead Down attracted community attention, and I wrote two popular articles explaining the project:

Armstrong, K, 2009b. Archaeological excavations at Yellowmead Stone Circles, *Dartmoor Matters,* The Dartmoor Preservation Association, Spring 2009, 10-11.

Armstrong, K, 2009c. Yellowmead stone circles, Sheepstor, *Dartmoor Magazine.* 94, 35-6.

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Glossary of peat terminology

Peat terminology synthesised from Koster (2005, 161-181) and Lindsay (1995, 8- 53)

Term	Definition
acrotelm	oxygenated, living, active layer of a peat bog, usually about 30cm deep
blanket bog	thin peat soil (usually less than 1m) that follows the contours of the land surface
bog	a UK term for an ombrotrophic mire
carr	northern British term for a wooded fen
catotelm	the accumulated peat below the acrotelm. Water transfers happen up to 100 times slower in this part of the bog
eutrophic	mineral rich environment/water source
fen	lowland mires with eutrophic or mesotrophic water inputs; may be eutrophic, mesotrophic, or oligotrophic
hydraulic gradient	a description of the movement of water within the catotelm and acrotelm of a bog or fen
hydroseral succession	the process of a sequence of plant communities overtaking each other in a lake as it gradually fills in and less water tolerant species can survive. The rates and plant types depend on the nutrient status of the water inputs
lagg	a network of steams at the edges of a mire that is the water flowing out of the base of the bog system; the zone where the bog water and ground water meet; sometimes have fen vegetation communities
liminogenous	mires developed along lakes and slow flowing streams/rivers
limnic peat	peat formed in open water conditions
macrotope	the whole bog ecosystem; a single hydrological unit
marsh	open grassy wetland ecosystem based on a mineral soil with no peat formation
mesotope	a sub-unit of a mire, for example in an upland raised bog complex, the saddle mire joining two raised basin mires.
mesotrophic	intermediate amount of minerals in environment / water source
microtope	a component small environment making up part of a mire, for example a single pool on a raised bog, or a single ridge.
minerotrophic	groundwater fed
mire	peat forming ecosystems other than lakes
moor	a poorly defined term; can mean the same as mire (i.e. be upland or lowland) but commonly used to refer to upland landscapes in the UK which may or may not be mires
oligotrophic	mineral poor environment/water source
ombrogenous mire	rain-fed mire
ombrotrophic	rain-fed
paludification	the formation of a mire over mineral soils (forest or grassland) or bare rock due to a rise in the local water-table
quagmire	part of the terrestrialization process in some systems; a thick floating mat of living vegetation forms over the water and peat accumulation continues beneath it
raised bog	a convex dome of bog-peat (ombrotrophic) formed over a relatively flat surface, above the original water-table. May develop on other mires
soligenous mire	mires formed on slopes and fed by water flowing through the soil
swamp	wooded wetland ecosystem based on a mineral soil with no peat formation
telmatic peat	peat formed in transitional conditions (open water- mire)
terrestrial peat	peat formed at or above the high water level
terrestrialization	the transformation of water into a peatland environment, by a process of hydroseral succession
topogenous mire	mire formed in a topological depression and fed by groundwater

List of abbreviations and units

Abbreviation/unit	Explanation
AIP	Archaeological Investigations Project
AONB	Area of Outstanding Natural Beauty
CRM	Certified Reference Material (in this case TH-2 from Environment Canada)
DCMS	Department for Culture, Media and Sport
DEFRA	Department for Environment, Food and Rural Affairs
DNPA	Dartmoor National Park Authority
EH	English Heritage
EM	Electromagnetic (used in this thesis to refer to Slingram systems)
ERT	Electrical Resistance Tomography
FDE	Frequency-Domain Electromagnetic
FM	Fluxgate Magnetometer
GIS	Geographical Information System
GPR	Ground Penetrating Radar
GSB	Geophysical Surveys of Bradford
HER	Historical Environment Record
ICP/ICP-OES	Inductively Coupled Plasma spectroscopy / Inductively Coupled Plasma Optical Emission Spectroscopy
LOI	Loss On Ignition (measurement of organic matter)
MAREW	Monuments At Risk in England's Wetlands
MC	Moisture Content
MHz	Mega-Hertz (unit of frequency measurement)
MS	Magnetic Susceptibility
mS/m	milli-Siemens per metre (unit of conductivity measurement)
NE	Natural England
nm	nano-metre (measurement of distance, 10^{-9} metres)
NMR	National Monuments Record
NNR	National Nature Reserve
ns	nano-second (measurement of radar travel time, 10^{-9} seconds)
nT	nano-Tesla (unit of magnetic field strength)
ohm	measurement of resistivity
PSD	Particle Size Distribution
RDP	Relative Dielectric Permittivity
SI	Systeme Internationale unit (dimensionless unit of measurement, used for MS readings)
SIP	Spectral Induced Polarisation
SMU	Soil Mapping Unit
SMR	Sites and Monuments Record
SSSI	Site of Special Scientific Interest

Section One: Background to the research

This section contains four chapters explaining the aims of the research project and situating it within its archaeological, geophysical and wider research context.

Chapter 1 is a short introduction that defines the problems to be addressed and discusses the overall research project in terms of simply stated aims, objectives, and outcomes. It will outline the predicted impacts of the research, in various spheres, and provides a summary of the structure of the whole thesis.

Chapter 2 will examine peatland archaeology, including the history of archaeological investigation in these environments. It will consider how archaeological remains are preserved in them, and the distribution of sites. Legislative protection will also be considered.

Chapter 3 will deal with peat, in terms of formation processes, physical and chemical characteristics, its distribution, and the threats these environments face. It will also look at peatland classification systems used by linked disciplines with an interest in peatlands.

Chapter 4 will look at assumptions made about the responses of peat, and consider geophysical prospection in peatlands used by other disciplines such as ground engineering surveys and measurements to value the commercial prospects of a peat resource. It will then look at some recent examples of successful archaeo-geophysical surveys in peatland environments that show the potential for site detection without destructive interventions.

Chapter 1: Introduction

Imagine if Flag Fen or the Sweet Track were discovered for the first time tomorrow, and we could produce geophysical surveys to show their extent, the major features and how they sat in the landscape. We might be closer to answering huge questions about these monuments that, in almost 40 years (in the case of the Sweet Track), we have been unable to answer, key questions about the nature and extent of the archaeological remains and the landscape they were created within. We might even be able to assess which parts of the archaeology are in immediate danger of desiccation or acidification, and which parts are pristine and in need of in-situ protection.

On dryland sites, the first response is commonly to commission geophysical surveys after a new discovery. Geophysical surveys can reveal archaeological remains invisible at the surface, they can find the edges of a site, and then can help to place it within a landscape context (Clark 1996, Gaffney and Gater, 2003). These are some of the most pressing concerns for archaeologists, particularly if a site is under threat. They need to know what might still be present, in terms of features, how large the site it, and what else in the area it might relate to.

However, geophysical survey is perceived to be difficult if not impossible in wetlands, and so geophysical survey might not be considered as a possible solution for these kinds of sites. This thesis deconstructs some of the preconceptions about the 'impossibility' of wetland geophysical survey, and suggests that geophysical prospection might also be a useful tool in helping wetland archaeology answer major criticisms that have emerged in the last 10 years.

Wetland archaeology had been championed as a panacea for prehistory, hailed by Coles in the mid 1980s as 'the only source of evidence worth pursuing' (1987, 18). It was suggested that wetland sites offered important insights into the material culture of prehistory, and that inferences could and should be made from them to dryland sites. The 'Wetland Revolution' was widely proclaimed (Coles 1996), with a belief that insights gained from the study of wet archaeology would radically alter our understanding of prehistory. Twenty years later, wetland archaeology as a discipline began confronting major criticisms. Van de Noort and O'Sullivan (2006, 9-21)

summarise these as being reliant on functionalist interpretations, denying prehistoric people agency by relying on environmental determinism, lacking in geographical and cultural context and remaining stubbornly a-theoretical in its approaches. These external perceptions, whether valid or not, have meant that wetland archaeology has not had the radical influence on wider studies of prehistory as had been hoped and argued for. They report an attitude amongst the wetland community that the archaeology is so rich, theoretical frameworks are not needed to interpret it. The community has recognised and responded to these challenges (Barber and Sheridan, 2007, 4). Though not perhaps entirely agreeing with them, the discipline of wetland archaeology has started to equip itself with the tools to overcome these barriers, whilst arguing that it does not need to be accepted by the mainstream for it to be a valid discipline.

Geophysical prospection may have a key role as a site and landscape investigation tool in this resurgence in wetland archaeology, but only if it can meet the challenges peatland environments pose.

1.1 The problem

Archaeologists have long been aware that peatland environments (along with other waterlogged deposits) are a rich source of information and artefacts simply not available from other, drier, contexts (Coles 1987, 12). The anaerobic nature of the peat means that organic materials are sometimes preserved in almost pristine condition, or at least as long as the environment is maintained. The problem is that most of these sites only come to light as they are being destroyed, as chance finds during engineering or extraction operations. These sites are largely invisible to conventional prospection techniques such as fieldwalking, aerial, photography, and topographical survey, especially in the lowlands.

The wealth of wetlands as an archaeological resource in the UK has been demonstrated by a number of surveys and overviews, largely in the form of four regional projects commissioned by English Heritage from 1973- 2000, the Somerset Levels Project, The Fenland Survey, The North West Wetlands Survey and the Humber Wetlands Project. These projects produced a wealth of individual publications and overviews, and lead to the production of a report on the state of the wetland archaeological resource, Monuments at Risk in England's Wetlands

(MAREW), and a strategy document explaining how English Heritage planned to tackle the problems facing these landscapes (Olivier & Van de Noort 2002; Van de Noort *et al.* 2002a)

Peatland archaeological sites are under constant threat, from commercial peat extraction, development, desiccation, climate change and changes in agricultural practices. In the past, peat extraction has at least offered an opportunity to discover buried sites, for example during the Somerset Levels Project, but as commercial peat extraction has slowed the threat has become more insidious, with drainage for agriculture and development desiccating the sediments and destroying the archaeology without it ever being exposed for examination.

The archaeological resource is extensive; in England and Wales alone the Monuments at Risk in England's Wetlands report quantified it as follows:

> *The identifiable archaeological resource of England's wetlands is estimated at 13,400 monuments, including:*
> - *1800 monuments in upland peatlands*
> - *4200 monuments in lowland peatlands*
> - *7400 monuments in alluviated lowlands*

 (Van de Noort *et al.* 2002a, 11)

The report then goes on to discuss the fact that in the last 50 years an estimated 2,930 wetlands sites have been totally destroyed and a further 10,450 are likely to have suffered damage, desiccation or partial destruction (Van de Noort *et al.* 2002a, 23).

At present, the English Heritage guidelines for geophysical survey in archaeological field evaluation state

> *The problems of depth of burial, as above, are accentuated by waterlogging; geophysical techniques can, as yet, have little part to play in wetland evaluation. Structural remains (such as pile dwellings, trackways etc) in organic sediments, in particular, are undetectable. Traditional dry-land geophysical techniques are best attempted in areas of relative dryness and shallow overburden ('islands' or*

wetland margins) and features so detected may then have some indirect bearing on the likely location of significant sites elsewhere obscured.

(English Heritage 2008, p.17)

Despite this pessimism, there is evidence that geophysical survey can work in these environments, and is therefore a possible way forward to the detection and mapping of the resource in peatland environments. The time is ripe for a study into not only what does and does not work, but *why*.

1.2 Aims and objectives

Given the need for a prospection tool for peatland environments in the face of the threats to the archaeological resource within them, the aim of this research is to examine existing geophysical survey tools and techniques, evaluate them, and devise accompanying guidelines for archaeological geophysical prospection in peatland environments.

Objectives:

1. Review the current state of this subject in Northwest Europe and understand what has already been tried and tested and which techniques require closer scrutiny
2. Develop a heuristic typology of peatland environments as a basis for characterising the conditions under which archaeological deposits and structures are preserved
3. Locate representative case studies to test the techniques across these environments
4. Characterise the expected archaeological targets and ensure the case studies reflect these
5. Test commonly available geophysical techniques in peatland environments
6. The interpretation and qualitative comparison of the results of those surveys
7. The verification of the interpretation of the surveys based on ground-truthing data
8. The combination of all results into a Geographical Information System (GIS) both for ease of retrieval and comparison

9. From the above, make an evaluation as to the most useful techniques for specific peatland environments and targets, taking into account ease and speed of survey, degree of certainty in the results obtained and by comparison with the usual avenues of investigation in these environments: trial trenching and boreholes

10. Laboratory investigations including geochemistry words 'and simulated surveys removed to help establish why certain techniques 'work' and certain techniques 'fail' to guide further development and innovation

11. Produce a series of recommendations as to technique and survey protocols for differing peat environments and archaeological targets, with an explanation of reasons for failure/success

12. Relate these findings to the wider application of geophysics in archaeology, particularly the need for more evaluation of techniques against ground-truthing and comparisons between different techniques and strategies.

Measuring success

Each of the following points is a measurable outcome towards the above objectives.

a. A full and current analysis of archaeological geophysics, wetland/peatland archaeology, near surface environmental geophysics and peatland ecology and chemistry in the form of a literature review (Objectives 1, 3-4)

b. A classification system for peatland environments specific to this frame of reference (Objective 2)

c. A classification of geophysical archaeological targets specific to this frame of reference (Objective 4)

d. A group of completed case studies that as a whole allow testing against all of the above classifications (Objective 5)

e. The reporting of those case studies to English Heritage, the Landowner, Local Historic Environment Record and the Archaeology Data Service (Objectives 5, 6-8)

f. The verification of the geophysical case studies against trial excavations or prior knowledge to allow evaluation of the various techniques (Objective 7)

g. Explanations for the success or failure of the techniques in each case study (Objective 10)

h. The production of a set of guidelines for surveying in peatland environments (Objectives 11 and 12)

1.3 Drawing out the questions

Meeting the aims and objectives of this research proposal will answer several important questions that are closely related to the measurable outcomes discussed above. They have been drawn out of the general aims, as the project has progressed, and as such have been arrived at inductively, rather than by following a hypothetico-deductive approach.

These are:

- Can conventional geophysical techniques be of use in the investigation of archaeological research (or development, or conservation) queries in these landscapes?

- If they work, exactly what properties of the peat and the archaeology are being detected? If they fail, what is causing this and can it be reliably predicted?

- Does the interpretation of geophysical data stand up to ground-truthing (either from interventions, or against 'known' sites)?

- What is the role for ground-truthing in these environments, given the problems associated with interventional techniques (see Chapter 4, Section 8 below)

1.4 Relevance of the research

The research reported here was conducted at a time of challenges and opportunities in peatland archaeology. In the UK, the large scale community or rescue projects that characterised the two decades spanning the mid '70's to the mid 90's have generally ceased, with the realisation of the large costs of excavation and conservation associated with these environments (Coles & Coles 1986; Coles 1991; Coles 1996; Pryor 2001; Van de Noort *et al.* 2002a), and as the obvious threats of destruction from commercial peat extraction have largely ceased.

In some ways, the boom in wetland archaeology in the 1970's and 80's was fuelled by commercial peat exploitation; without the peat companies, the archaeology in the Somerset Levels would not have come to light, but on the other hand, nor would it have needed rescuing. The threats to these sites in the UK (and elsewhere-commercial extraction continues in Ireland and Finland, for example) have not ended though. They are at risk for far less obvious damage such as dewatering, either by deliberate drainage for agriculture or development, or from climate change. These risks are, in some ways, more insidious as the archaeology is destroyed *in situ*, never seeing the light of day; never being 'discovered' so that it can be rescued. In a review of the history of wetland archaeology, Coles & Coles (1996) showed that most of the significant discoveries of the last 100 years have been found during some form of peat cutting, and only one (in a lake, rather than buried in peat) have been detected by any non-invasive means:

Site	*Discoverer*
Key Marco	muck digger
Star Carr	amateur archaeologist
Friesack	archaeologist and old sighting
Noyen	archaeologist exploring Neolithic site
Windover	builder
Torihama	dredger
Sweet Track	peat digger
Hauterive	archaeologist and old sighting
Hornstaad	archaeologist and old sighting
Alvastra	builder
Biskupin	school teacher
Llyn Cerrig Bach	Royal Air Force during ground clearance
Nydam	peat cutter
Lindow, Tollund *et al*	peat cutters
Ballachulish	wall builder
Charavines-Colletiere	lifeguard and early reports by fishermen
Glastonbury	medical student/antiquarian- excavations
Monte Verde	geologist, excavation after exposure during logging
Ozette	native people (tradition regarding sites' existence)
Kuckhoven	machine driver during archaeological survey
Huseby Klev	archaeologist exploring Iron Age site
Flag Fen	Archaeologist during dyke survey

(Summarised from Coles 1996, 155, with additions, n.b. many of these are lakeside sites)

As the list demonstrates, most of these findings are chance discoveries, or an archaeologist working from a recorded discovery by someone working in the peat. Only one of the sites has come to light from aerial prospection, and only one from archaeological area survey. As highlighted by Utsi, investigations in these environments are often keyhole or small scale. Ballachulish Moss, on the shores of Loch Leven in Northwestern Scotland, was the site of spectacular finds of prehistoric wood including a person sized idol, casks of bog butter, and a wattled structure in the 19th century(2003, 178). However, the existence of platforms out in the marsh was unknown until Ground Penetrating Radar (GPR) was employed at the site in 1996 and 1998 (Clarke *et al.* 1999a; Utsi 2004).

As discussed below, the updated English Heritage guidelines for geophysical survey in archaeological field evaluation (English Heritage 2008) call for further investigations of the potential of GPR surveys in these environments, but beyond acknowledging some progress with GPR and other highly specialised survey techniques, the picture has changed very little since 1995, when the first set of guidelines were issued.

> *The problems of depth of burial, as above, are accentuated by waterlogging;* **geophysical techniques can, as yet, have little part to play in wetland evaluation**. *Structural remains (such as pile dwellings, trackways etc) in organic sediments, in particular, are undetectable. Traditional dry-land geophysical techniques are best attempted in areas of relative dryness and shallow overburden 'islands' or wetland margins) and features so detected may then have some indirect bearing on the likely location of significant sites elsewhere obscured.*

(David 1995, 12 emphasis in original).

This discouraging statement is retained intact in the more recent edition of the document, but prefaced with a slightly more encouraging discussion of the potential of GPR. It is plain that the geophysical response of GPR needs to be better understood with respect to archaeological targets in wetland environments.

Furthermore, in the last ten years, some highly specialised prospection methods have been developed for wetland environments, showing there are exploitable differences in the physical properties of waterlogged archaeological materials, compared to their surrounding matrix of peat. These successes, and the trend towards more highly detailed and accurately measured surveys, mean that there is a great opportunity to investigate the more commonly employed techniques, so long discounted because of some failures of detection, and to see how today's instruments and methods compare.

Although a number of conventional surveys have been attempted, in the UK very few of them have met with strong, tested success. The possibility that the surveys would produce no results was not considered as a risk for the research project; the focus has been on looking at the reasons for the geophysical responses being created, rather than the absolute 'success' or 'failure' of a technique in terms of anomaly detection. Even if all of the case studies produced negative results, the explanation of these would still have been a useful contribution to knowledge in this field.

This project will also outline the call made below for more investigation of the GPR response in these environments, with ground-truthed surveys, directly answering the challenge made by English Heritage.

1.5 Impact of the research

English Heritage state that:

> *Some case studies … indicate that GPR is also capable of detecting potentially significant anomalies in peat, and there are reports that wooden trackways or other structures may be detectable… there is a need for further experimentation, and reference to ground-truth before GPR can be recommended as a routine approach in these circumstances.*

(English Heritage 2008, 17-8)

Other work (Tabbagh 1986; Johnston & Wickstead 2005; Weller *et al.* 2006) indicates there are numerous possible avenues of exploration in these environments, not just GPR. The impact of this research will be to answer that call for thorough ground-truthed surveys of GPR and other generally available techniques so that

meaningful and useful comparisons can be made between them. The call for more feedback and ground-truthing data for archaeological geophysics in general, is made elsewhere in the literature (Gaffney & Gater 2003, 182). It is necessary to understand not only which environments particular techniques are suitable for, but also to explain why, so that other practitioners can approach peatland environments with a greater degree of confidence.

The ultimate output of this research is a framework for the selection of geophysical techniques for survey in peatland environments, based on both the specific environment and the predicted archaeological targets. This framework is underpinned by a sound understanding of the reasons for the success and failure of a range of techniques in different environments and against a range targets, with reference to detailed case studies and ground-truthing data.

This will allow archaeological geophysicists to prospect in peatland environments with confidence in their chosen approach, rather than the current climate which, as indicated by the words of English Heritage, cited above, has been very much a hit-and-miss situation. Wetland archaeology also needs more tools for landscape-scale investigation, if it is to take up the challenge to re-engage with the theoretical debates in the wider discipline (Van de Noort & O'Sullivan, 2006).

There have also been significant impacts for each of the case study sites; to test the techniques against real archaeological challenges each case study sets out to answer a site specific archaeological question. Our knowledge of the archaeology and physical environment of each site has been increased by this work, and all of the case studies have been reported to English Heritage, and where appropriate the local SMR, meaning these case studies are now part of the archaeological record.

1.6 Overall methodology

The overarching methodology of this research was to first make a critical appraisal of what was already known, or assumed about peatland environments, and geophysical survey in them in particular. This supported objectives 1 to 4, and assisted in the classification and selection of case-study sites. One of the conclusions at this stage of the research was that, too often, a single technique was employed to survey a site.

From a review of geophysical practice, conventional techniques were identified that either had a large take-up and understanding in the geophysical community, or demonstrated potential, but did not involve the need for technological innovation or modification. It was important to test multiple techniques at each case study site in order to make fair comparisons between their detection capabilities, as conditions in one environment might favour a particular method over another.

Surveys at the case-study sites were completed and interpreted based on understanding gained during the critical appraisal of the literature on peatland archaeological sites, and what previous geophysical surveys had concluded. This was complicated by a general lack of published ground-truthing work in this area.

Selected sites were therefore subjected to targeted ground-truthing investigations and follow up laboratory work to characterise the soils, peat and sediments, and to give insights into how geophysical anomalies were being produced and detected.

In an iterative process, the original survey interpretations were then re-visited in the light of the ground-truthing information, and appraisals made about the relative merits of the different techniques for the environments studied.

1.7 Summary of thesis

This chapter has provided an overview of the project in broad terms, defining the archaeological problem and examining the aims, objectives and hoped for impacts. It has also given a view of the overall methodological approach. This final section of the chapter provides an overview of the structure of the rest of the thesis.

Section 1
The further chapters in Section 1expand on this overview. Chapter 2 looks at the relationship between peat and archaeology, including an overview of the history of peatland archaeology in northwest Europe and a discussion of key sites. Chapter 3 looks at the properties of the peat itself, and covers it's formation, chemistry and the classification of peatland landscapes, and their distribution in north west Europe. Chapter 4 deals with a short overview of archaeological geophysics, examining the perceived problems with surveying in these environments, a critical review of

archaeological surveys that have already been carried out and approaches from other disciplines such as engineering to peatland. Finally it briefly examines data integration and validation methods in the context of peatland surveys.

Section 2

Section 2 is concerned with the methodologies of the project, both the research design of the project and the technical aspects of the geophysical techniques, laboratory methods and data processing methods employed within the research design.

Chapter 5 looks at peatland classification methodologies and builds a pragmatic classification scheme for this piece of research, and goes on to explain the selection of the case study sites and how they fulfil the aims and objectives.

Chapter 6 deals with each of the geophysical techniques employed in turn, providing a summary of the physical principles of the soil matrix they examine, their strengths and weaknesses and a discussion of the specific equipment selected where appropriate.

Chapter 7 explains the principles and details of the various data processing an display methods employed, and Chapter 8 looks at the role of ground truthing within this research project and in archaeological geophysics in general.

Section 3

Section 3 contains four chapters, each dedicated to a specific case study area, with a subsection for each of the 8 specific sites. They are organised in a standard structure that outlines the site background, the specific aims of each case study, the specific techniques, instruments and settings employed and the results that were obtained, and the conclusions of the geophysical surveys.

Each chapter also reports on any ground truthing work carried out, and contains an overall evaluation of the performance of the geophysical techniques in that particular environment type (as defined in Chapter 5).

Section 4

Section 4 discusses the surveys in the context of the background established in sections 1 and 2, and moves on to examine conclusions that can be drawn from the research presented here. Specifically, Chapter 13 has a broad ranging discussion of current themes and challenges in wetland (and by extension, peatland) archaeology,

and archaeological geophysics, and the results and conclusions of the case studies in this light. Chapter 14 draws conclusions to the questions originally posed in Chapter 1, and measures the success of the project against the aims and objectives set out above. Finally it presents the 'toolkit' for archaeological geophysical prospection in peatland environments, and suggests areas of future research that need to be addressed as a priority.

Chapter 2: Peat and archaeology

2.1 Introduction

Peatland environments are especially significant for archaeologists because they often preserve organic material of the kind not found on 'dry' sites. This ranges from cultural objects and human bodies down to microscopic indicators of past climates. The wet, anaerobic conditions that allow the peat to form also prevent the decay and breakdown of anthropogenic organic material (Coles & Coles 1986; Coles 1990; 1991; Coles 1996; Darvill 2002). The exact physical and chemical mechanisms of preservation are not yet fully understood, but there is broad consensus that it is a combination several factors. The anoxic environment limits biological activity, as do the typical pH values, chemical species and temperatures. The anoxic environment is maintained by very slow water movement through the sediment, as water is oxygenated by turbulent movement. The availability of oxygen to chemical reactions and bacteria is also a factor (Clymo, 1983, Caple 1994). It is not just the macro-scale artefacts that are valuable; peat is especially valuable for palaeoenvironmental reconstruction as it preserves seeds, plant fibres, and pollen in stratigraphic sequences that allow assessments of the environment within and around the bog (Howard-Davis *et al.* 1998; Dincauze 2000; Van de Noort *et al.* 2002b; Simmons 2003; Bindler 2006). Furthermore, because it is organic, the peat itself can be radiocarbon dated, giving absolute dates to horizons within pollen sequences, and the onset of peat formation, which can be a climate indicator (Frenzel 1983).

2.2 Peat and archaeological deposits

A thorough exploration of the current state of research into the physical and chemical properties of peat is required. This will be fully discussed in Chapter 3; this section here deals simply with the chemical properties of peat environments that make them so important to archaeologists.

A precondition of peat formation is that the soil needs to be permanently waterlogged, with the local water-table being at or close to the surface for most of the year. In raised bog systems (see below) the water-table can be artificially raised by the peat

ecosystem, as the hydrophilic plants that make up the bulk of the peat retain water well above its 'normal' height. This waterlogging is essential for the formation and maintenance of the plant communities that sustain peatland environments, but it has two important consequences. Firstly, the anaerobic conditions that quickly develop below the permanent water-table inhibit microbial and microfaunal activity, meaning the usual processes of decay are inhibited as the organisms that feed on rotting organic material cannot exist without oxygen. Chemical decomposition is also inhibited as it usually needs oxygen as part of the chemical process. For a number of reasons (see Chapter 3) peat bogs are usually (though not always) acidic systems; this also inhibits the decay process as macrofauna do not readily tolerate acid environments. Thus there is little or no bioturbation to introduce oxygen and break up material(Clymo, 1983, Lindsay 1995, Koster & Favier 2005).

If the environment becomes too acid, this can be detrimental to the preservation of some types of organic material, especially bone and antler (Caple 1994). The increasing acidity at Star Carr is a concern for archaeologists working there as it is potentially destroying the Mesolithic antler and bone finds for which the site is rightly famous (Boreham *et al.* 2009). In this case increasing acidity seems to be the result of greater seasonal fluctuations in the water-table due to an increase in local drainage; an example of the sort of threat faced by these environments. We are only aware of the potential losses on this site, and the need for mitigation, because it is already known to archaeology and the focus of current research. There are, according to the MAREW report (Van de Noort *et al.* 2002a), potentially thousands of sites like it in the UK which could very well be destroyed without ever being known to us, or are already lost.

Once those anaerobic conditions are breached, either by direct exposure or dewatering, organic archaeological remains rapidly decompose as the presence of both moisture and oxygen is conducive to the decay process.

2.3 Landscapes and site types

There are connections between the development of peatland landscapes and human interaction with them (Van de Noort 2002a; Van de Noort & O'Sullivan 2007). This relationship governs the types of archaeology we might reasonably expect to encounter in these environments. A much more detailed account of the development

processes and timescales of peatland formation (particularly in the uplands) is made in Chapter 3. This section gives an overview of the types of site associated with wetland environments in Northwest Europe. For reasons outlined in Chapter 5, this research project uses upland vs. lowland as primary distinction between peatland environment types. Peat development and human exploitation have different characters in each of these two categories.

In the lowlands, peat development generally seems to start with the end of the last glaciation, as warming encouraged plants to start to colonise formerly glaciated or periglacial areas, and as river systems became established. Where conditions were right, peat developed where waterlogging of existing soils started, or as a process of terrestrialization in slow moving or stagnant water systems, such as kettle holes.

Wetland environments have frequently been exploited by humans; some wetlands are incredibly rich natural resources, home to a myriad of plant and animal species that would have been very useful to Mesolithic communities and all of those that have followed. For example, there is evidence for hunting, such as arrow points, structures that may have been hides, tools, and other, more ritual aspects of human interaction with the landscape in the Mesolithic finds from Ballachulish Moss (Clarke *et al.* 1999a; Utsi 2004), Star Carr (Conneller 2004) and Friesack in northern Germany (Van de Noort & O'Sullivan 2006, 45). Such is the presumed lure of these landscapes, that English Heritage assumes a human presence in all of them, in all periods, in the UK:

> *All wetlands were valuable resources and retreats for human populations, and carry the continuous record of human activity throughout the ages. A human presence of some sort must be therefore be assumed in any and all wetlands, whether it is easy to identify or not.*

 (Olivier & Van de Noort 2002, 2).

This assertion has been challenged in the recent literature, arguing that raised bog in particular has low biomass production and biodiversity, and so may have been less attractive to past communities than the above generalisation across all wetland types

implies (Van de Noort 2002a; Van de Noort & O'Sullivan 2006; O'Sullivan & Van de Noort 2007; Van de Noort & O'Sullivan 2007). This is part of a wider critique of the generalism, environmental determinism and internationalism that has arguably persisted too long in wetland archaeology. Nevertheless, there still good grounds for assuming human activity in most wetland landscapes, though these perhaps need to be framed less in terms of economics and exploitation, and with more specific attention to the culture and context of the society being examined.

Once people settled in the landscape and started farming, hunting and gathering continued to form an important part of the domestic economy. All over Europe there is strong evidence for prehistoric farming communities choosing to live at the periphery of these areas, along 'ecotones'; boundary zones between environments that allow exploitation of more than one sort of landscape. For example, at Flag Fen, there is evidence for settlement along the fen edges dating back to the Neolithic, with droves out into the fens presumably used for livestock grazing in the summer months. This occupation pattern continued right up until the drainage of the fens for arable agriculture during the later Middle Ages (French 2003a). In the Somerset Levels, there are trackways dated from the Neolithic to the later 1st millennium AD. The same can be said of bogs in Ireland, and in the much larger scale lowland peatlands of central northern Europe, such as the Federsee in Germany (Schleifer *et al.* 2002; Weller *et al.* 2006). In other places, wet lakeside locations seem to have been selected as fortifiable locations, either on a small scale, such as the crannogs in Scottish lochs or the great fortified settlement of Biskupin in Poland, and other Lusatian sites (Coles 1996).

The non-functional aspects (i.e. 'ritual' or religious) uses of these landscapes and the structures within them are being increasingly recognised and explored. For example, it has been suggested that some of the finds recovered along the length of the Sweet Track were ritually deposited rather than lost or discarded (Coles & Coles 1986); Bronze Age trackways have been discovered with bronze hoards along their route (Tabbagh 1986), and it seems likely that the entire complex at Flag Fen had a more religious purpose than domestic one, and objects seem to have been deliberately broken or 'killed' and placed in the waters there (Pryor 2001). Perhaps the most famous of all wetland archaeological discoveries are the bog bodies that have been

found over the years. With some of them (e.g. Lindow Man- England and Tollund Man- Denmark), some sort of ritual execution seems to have taken place, with a specific last meal and a deliberate treatment of the body (Coles & Coles 1989, 173-94). Lowland wetlands seem to have been special places in the European psyche, and to some extent they still are, with myths being passed down to us in the 21st Century describing them as otherworldly, a place where you might, for example, be more likely to encounter the dead, or dangerous or mischievous spirits. Tolkien seems to be drawing on this cultural resonance in his description of the Dead Marshes, the principal route into Mordor, where the protagonists are tempted to join dead warriors lying in pools in the bog by corpse-candles (Tolkien 1954). Kelpies are a particularly nasty Scottish myth; evil horses who will drag you under the water to eat you. Grendel and his mother in the epic poem Beowulf dwell in a swamp, the Afanc (dragon/serpent) that killed Arthur, and his mysterious lady of the lake; all come from marshy places. The fascination these environments pose to authors and poets is also evident in the works of Seamus Heaney, who experienced a particularly strong personal reaction to the Tollund man (Heaney 1999). Bog-bodies as a subject of literary inspiration has been a topic of discussion at archaeological conferences (Finn, 1999).

Contrastingly, the uplands did not start the Holocene as they appear today. In the Flandrian, the consensus is that there was mixed forest as high as growth seasons and temperatures permitted it (Flemming, 1988, Simmons 1996, 2003). Though arguments are starting to be advanced that this forest was not as all encompassing as once thought, it nevertheless existed during the Mesolithic. There are arguments that the process of upland deforestation began in the Mesolithic, perhaps as a combination of human exploitation (using fire to create and maintain clearings for better hunting), and a shift to a slightly wetter, colder climate (Flemming, 1988, 120, Simmons 1996). By the Bronze Age, the uplands were deforested, and developing into the landscape we see today (Lynch 1996). During this period some areas sustained relatively large communities of farmers. On Dartmoor, for example, there seems to have been a pattern of enclosure of the lower slopes, and the open moor seems to have been used for grazing (Flemming 1988). These settlements had large funerary and ritual complexes associated with them, and seem to have been abandoned in the early 1st millennium BC, along with other upland areas (Darvill 1988, 127). Other upland

landscapes in the UK may have been less spectacularly enclosed, but show just as much evidence of routine occupation and exploitation that seems to reach a peak, and end, in the later Bronze Age, with a retreat to lower slopes and hillfort sites in the Iron Age (Cunliffe 1986 30-32). It seems that during this period changes in the climate and perhaps over exploitation of the soils meant that these upland communities were no longer sustainable, and that these changes seem to coincide with an increase in the deliberate deposition of objects in wet environments, (Darvill 1988, 127) even in the uplands, such as bronze cauldrons deposited in Lyn Fawr in Wales (Cunliffe 1896, 32). More recently, Johnston has cautioned against the environmental determinism implicit in this interpretation and insisted that it is important to situate broad scale climate change within regional histories (2008, 278-9).

This disparity between the use of the landscape and peat development means there is a strong contrast between the archaeological targets in these two peat environments. The upland sites tend not to preserve much in the way of organic materials as they were inundated by peat after they ceased to be occupied and construction was usually in stone. Furthermore, the generally acidic soil conditions have destroyed much of the pottery and bone artefacts. Typically, only stone buildings, earthworks, and lithics remain.

2.4 Peat, policy and law

This section briefly examines the protection of peatlands under laws and international conventions, and then goes on to examine how it is treated in the UK in heritage policies and national legislation.

2.4.1 Protection of peat

Internationally, the most important convention regarding peatland environments is the Ramsar Convention on Wetlands of International Importance. This is a long-standing international convention, adopted by the UK in 1976. There are now146 protected Ramsar sites in the UK, but each tends to be small in area. This is because the sites were initially selected with a focus on maintaining migratory bird habitats. The convention means that the government agrees to protect and maintain the wetland, exhorting for their 'wise use'. The convention covers all types of wetlands including

some of the lowland peat environments that this study covers (Joint Nature Conservation Committee, 2009).

In addition, under UK national law, sites may be protected under various national schemes like Areas of Outstanding Natural Beauty (AONB) or Sites of Special Scientific Interest (SSSI). Indeed, some sites might have multiple classifications. The Sweet Track, for example, is protected in its own right under the Ancient Monuments and Archaeological Areas Act 1979. But it also lies within a wetland complex that is a Ramsar-designated wetland, a National Nature Reserve (NNR) and a Site of Special Scientific Interest. Much conservation legislation is aimed at conserving the specific ecosystem, protecting biodiversity and in some cases trying to improve the environment, or mitigate damage.

SSSI designation means that consent from Natural England is required before certain types of activity can be carried out, or significant changes made in agricultural practice. NE also monitors SSSIs and may pursue legal action to enforce good management by the owner (Natural England, 2009b). All terrestrial Ramsar sites in the UK are also designated as SSSI. Particular emphasis is placed on ensuring the hydrology of wetland sites is not adversely affected (DEFRA, 2006).

AONB designation is slightly more complex, and can involve large landscapes with multiple owners and councils. AONB protection is designed to 'conserve and enhance the natural beauty of the landscape', whilst allowing those who live and work there to maintain livelihoods and ways of life. This is largely enforced through planning controls and financial initiatives such as grants from DEFRA to assist in maintaining traditional farming methods and landscapes (Natural England, 2009b).

2.4.2 Peat and policy

In the early 2000s English Heritage published a strategy document detailing their high-level response and recommendations for the best management these environments. This was the culmination of around three decades work assessing, and in some cases rescuing, the archaeology in (predominantly) lowland wetlands. Highlighting the strong likelihood of archaeological remains being present within wetland environments, it included broad level strategies themed around management,

outreach/education, procedure/policy and research. It also encouraged the protection of significant archaeological deposits that could not be scheduled under the current scope of the legislation by using environmental designations instead. It explicitly recognises that generally speaking, ecologists and archaeologists desire the same things for these environments, and suggests archaeologists look to conservation ecologists for expertise in site management (Olivier & Van de Noort 2002). This report influenced regional research strategies, such as the one published by Hodgson *et al*. in 2005 for the prehistoric period in the Northwest of England, and has led to a greater interest and commissioning of geophysical surveys in upland areas (Dean 2003; Johnston & Wickstead 2005; Quartermaine *et al.* 2007).

2.5 An overview of Northwest European sites

The use of the term 'wetland' does not exclusively refer to peatland sites; it also encompasses peri-marine sites, whether or not they involve peat. It also covers sites in lake marls and waterlogged contexts that have developed without peat formation such as riversides and watermeadows. The boundaries between these environments are not always clear; as will be discussed in Chapter 3; the sediment sequences in wet environments can be complex and interleaving. It is possible that sites that were laid down in lake marls have since become buried in peat; such as some of the lake villages and some crannogs. Therefore, when looking at the history of peatland archaeology, we can generally consider the literature that examines 'wetland' archaeology, as there are few sites that come into the wetland category that do not, at some point, involve peat. See Figure 2.1 for the locations of key sites discussed in this section.

There is an excellent overview of the history and state of research in wetland archaeology in the mid 1980s in Coles' opening Chapter (1987) of *European wetlands in prehistory* (Coles & Lawson 1987). This volume was produced at the height of the self-proclaimed 'wetland revolution' (Coles 1991) and contains a lot of detailed information about past and current wetland archaeological sites, and the practices that were being developed to explore them. The validity of the 'revolutionary' claims about this field of research have already been discussed above in Section 1. Whatever the issues surrounding the explosion of wetland/peatland archaeology in the late 1970s and early 1980s, it did have some impact on our collective understanding of prehistory, and opened up access to new areas of prehistoric life for research.

However, these environments were not new to archaeology. Research groups like the Somerset Levels Project acknowledged this explicitly in their work. They were building on investigations that had been going on since the mid 19th century.

Peat had long been known as a source of prehistoric artefacts; there are examples recorded from the Middle Ages with an account of a bog body from Bondsdorp in Germany (Coles & Coles 1989, 10) in AD 1450. Often, the earliest explorations of wetland sites were chance finds by peat cutters reported to local authorities and then later antiquarians and archaeologists. There were also artefacts reported during enclosure and drainage work for agriculture and settlement expansion in the late 18th and 19th centuries. These included boats, like that found near the Clyde in 1780 in Scotland (Coles & Coles 1989, 13), weapons, textiles, and baskets (Coles 1987).

The first archaeological excavations at wetland sites in Europe focused on the Swiss Lake Villages, at sites like Auvernier and were conducted by Ferdinand Keller in the 1850s, and onwards. This early 'boom' in wet archaeology was prompted by the lowering of the water level in the Lakes in the mid 1850s, another example of wet sites coming to notice as they are being exposed and damaged (Egloff 1987). Shortly after, Robert Munro began working on crannogs in Scotland, as well as looking at other wetland settlements elsewhere in Europe.

Keller and Munro probably provided the inspiration for Arthur Bulleid to start looking for similar types of settlements in the Somerset Levels. In the first decade of the 20th Century he built on their work investigating the Glastonbury Lake Village, improved on their recording systems and worked with other scientists from the Royal Society producing environmental reconstructions which have withstood the test of time.

In the 1930s a major site was discovered at Biskupin, a fortified Lusatian settlement, on a peninsula in a lake near modern Gdansk in Poland, that contained somewhere between 102 and 106 timber houses, and was constructed in the early Iron Age, c.700-400 BC. This site was totally excavated and showed that large scale excavations on these types of site were possible and yielded a great deal of insight and information about the cultures that produced them.

In between these periods, discoveries continued to be made in peat bogs across Europe, of trackways, settlements, bodies and more enigmatic finds. Much of the organic material discovered during this period is lost as the necessary conservation techniques simply did not exist. There was also a long period of excavation at the Neolithic settlement site Alvastra, in southern Sweden, and work continued in the Alpine lakes.

Investigations continued, with a lull during the Second World War, with chance discoveries during peat extraction and during periods of low water in lakes, with little in the way of research design or overall strategy, with a notable exception in the form of the Fenland Research Committee, which involved Grahame Clark and Harry Godwin, who were among the founding fathers of modern British archaeology and environmental archaeology, influenced by the developing science of palaeo-ecology in Scandinavia. The committee ended in 1940, but their work informed Clark's work in 1949-51 at Starr Carr (1971), a Mesolithic site, which, Coles & Coles argue, marks the start of 'modern' wetlands research (1989).

The 1950s saw a greater interest in wetland archaeology for a number of reasons. Firstly, pollen analysis and environmental archaeology were starting to come of age, making wetland and more specifically peat sites targets of research. The development of diving gear helped with lake-bed and offshore investigations as archaeologists could now dive down to sites and work on the bed without having to build elaborate coffer dams or wait for the right tides or environmental conditions.

Major discoveries from this period include the afore-mentioned Starr Carr, and the Tollund and Grauballe bog bodies, which, thanks to advances in conservation techniques and archaeological science, yielded unprecedented information about the way they died, their last meals, and the conditions which had led to their remarkable preservation. There was a great deal of public interest in these discoveries, with a BBC reconstruction of their last meal (Coles & Coles 1989, 180-184). At the same time, the interpretations of the 19th century were being challenged; Keller had described the Lake Villages as 'pile dwellings' with platforms being constructed over open water and connected to dry land by bridges. We now see these sites as having

been formed on wet ground, subsequently inundated by lake waters (Coles & Coles 1989, 54), though pile dwellings have been recognised elsewhere in the Alpine region, for example, at Fiave and Lavagnone in the Italian Alps (Perini 1987).

The 1970s brought, in the UK and elsewhere in Europe to differing extents, increased pressures on wetland environments with agricultural, settlement, and industrial expansion, and increased demands on peat as a fuel source and for horticultural uses. The processes of peat extraction had also become mechanised, increasing the capacity for removal of the protecting overburden. With the growth of rescue archaeology as a concept in this period, and the increasing pressure on these environments, in the UK there was a surge in wetland archaeological sites and projects from the mid 1970s onwards. This has been discussed already in the introduction but it is worth noting that this period gave us both the Sweet Track and Flag Fen, as well as long standing research projects like the Somerset Levels Project and the Wetlands Archaeological Research Project.

In the UK, Bryony and John Coles have been the principal architects of this 'wetland revolution'. In their numerous publications on the subject (Coles & Coles 1986; Coles & Lawson 1987; Coles & Coles 1989; Coles 1990; 1991; Coles 1996, to give some examples), they have identified several site or find-types:

- Occupation which includes lake villages, pile dwellings and fortified peninsula/platforms like Biskupin, crannogs and coastal, riverside and estuarine occupation sites from the Palaeolithic and Mesolithic.
- Communication, including roads that date from the earliest trackways like the Sweet Track and those in the Federsee (Schleifer *et al.* 2002), through the corduroy roads from Iron Age sites in Ireland like Corlea (Raftery, 1986) and elsewhere, to the remains of vehicles used to traverse them, and boats used on inland and coastal waters, like those already mentioned from the Clyde.

The final category is more complex, and often intertwines with the other two; and indeed some sites have moved between categories or sit uncomfortably across them. 'Ritual' is a contested term in contemporary archaeological thought, viewed as perhaps a lazy categorisation of activities which do not fall into functional categories,

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and a way of escaping making difficult interpretations (Bruck 1999; Bradley 2003), but there are sites and finds which are clearly religious or funerary in their primary role. There is, for example a long tradition in prehistoric ritual or religious practice in western Europe, particularly during the Bronze and Iron Ages of 'votive' or sacrificial deposits in watery contexts, which includes peat bogs or former watercourses which have been inundated by peat (Darvill 1988, 127, Harding 2000, 326-33). Bog bodies, whether sacrifices, or murder victims, or executions come into this category, such as the Lindow, Tollund and Grauballe men, and the young girl of Windeby in north Germany (Coles & Coles, 1989, 177-91). Whole sites do as well, for example Flag Fen, originally thought to be a settlement site on an artificial platform in the wettest part of the fen (Coles & Coles 1989, 137-138), has been reinterpreted as a major ritual site, with little or no evidence for habitation during the Bronze and Iron Age (Pryor 2001). Some sites blend the two categories, like the ford-shrine, 'ritually' destroyed at Oldenburg, Lower Saxony (Hayen 1987). Fiskerton, in the UK is a trackway, but it is associated with votive deposits and seems to have been renewed during years that had full lunar eclipses (Field & Parker Pearson 2002). There are also single finds, and hoards that may be 'votive' ritual deposits or 'practical' hoards that were never recovered, or chance losses. These range from the mundane to the spectacular, including; the Gundestrup Cauldron, a 1st Century BC silver cauldron with decorations of supernatural beings, sacrifices and processions (Berquist & Taylor, 1987); wooden human figures from all over Europe such as the Ballachulish figure (Harding, 2000, 322); dogs are also widely known (found at Flag Fen, for example (Pryor, 2001, 428)), along with weapons and domestic items, sometimes in complex groupings, like the Hjortspring war canoe, buried with swords, spears, shields and chain mail on the island of Als in the Iron Age (Coles & Coles 1989, 192).

It does seem that there is a bias in the framing of sites between the UK and the rest Europe, with prehistoric wetland *constructions* being more readily recognised as 'ritual' rather than settlement. It seems likely that this bias is in the interpretation of the record, and the nature of the sites so far discovered than any major differences between the UK and the rest of Europe in terms of prehistoric building traditions, perhaps based on a greater willingness to engage with theory and more openness to the discussion of 'ritual' behaviour in the UK discipline.

Chapter 3: Peat

3.1 Introduction

In the most loose terms, peat is defined as '*unconsolidated material that largely consists of slightly decomposed or undecomposed organic material*' (Koster & Favier 2005, 161). Peatland is '*a general term referring to all kinds of drained or undrained areas with a minimal thickness of peat of at least several decimetres*' (Koster & Favier 2005, 161). When reading the archaeological literature, this should be cross-referenced with the definition of wetlands; '*all kinds of wet soils or shallow waters from fresh water lacustrine to salt marine environments*' (Koster & Favier 2005, 162), as the two terms are used interchangeably. There are several schemes for further classifying peat soils and peatland environments, which will be examined in detail in Chapter 5.

There is a relatively specialised terminology for peat, and there is a glossary of terms used in this discussion provided on page 15, though it is not an exhaustive list of all terms used in the literature.

Whilst the exact meanings or boundaries between some of the types and terms are not agreed upon (Koster & Favier 2005, 162), the definitions given above will be the ones employed for this piece of research. For example, mire type-names vary between the UK and the US, and different European languages have their own equivalent terms.

3.2 Peat environments and classification schemes

There are several schemes for classifying peat soils and peatland environments, which will be examined in detail in Chapter 5. However, it is important to clarify some of the basic distinctions that are widely recognised and adopted, particularly in the UK, as this is where the case study sites are located.

3.3.1 Overall divisions

There are multiple alternative classification schemes for peat, depending on, for example, where in the world you are researching or whether you are approaching the peat from a hydrological or biological perspective (Lindsay 1995; Haslam 2003, 57-103; Koster & Favier 2005). The definitions are by no means settled or agreed upon, and there are variations, for example between soil scientists, and biologists in the way they see things. Most follow a basic distinction between liminc and terrestrial peat, as outlined in Figure 3.1, but designate further subtypes, perhaps based on the development sequence of the landforms, or the plant community it supports, depending on the emphasis of their respective discipline.

In essence, there are three types of peat, which form two 'superclasess' of peat soils. **Limnic** peats are formed in lakes or slow moving water when organic matter is transported into the lake and falls to the bottom, gradually building up. **Mires** are the other 'superclass' and are either *telmatic*, where peat forms under swampy conditions with partially submerged vegetation, or *terrestrial*, where the peat forms at or above the high water level (Burton & Hodgson 1987). **Mires** with *terrestrial* peat are sometimes referred to as *ombrogenous*, as they are rain-fed. *Topogenous* and *soligenous* peats can be *liminc* or *telmatic* and may develop *terrestrial* raised bogs (Burton & Hodgson 1987; Koster & Favier 2005). These are formed due to the accumulation of water under the influence of local topography. A **mire** is also defined as 'undrained virgin peatlands with living peat forming vegetation' (Koster & Favier 2005, 161), though in the UK this can also includes peat in recovery, such as at Shapwick Heath.

With reference to the UK, **Mires** are conventionally split down into a further two classes, and three subclasses. **Minerotrophic mires** are fed by water supplied from ground water run off and rivers and they form both *telmatic* and *terrestrial* peat. These are commonly called '**fens**' in the UK. The water can be *oligotrophic* (nutrient poor), *eutrophic* (nutrient rich) or *mesotrophic* (in-between). **Ombrogenous mires** are fed by rain water and so are usually oligotrophic and form *terrestrial* peat. They split into two subclasses; **raised bog**, which forms in a depression and then grows above the ground level and **blanket bog**, which forms over a land surface where net

water input is greater than the drainage capacity, resulting in a waterlogged layer. In the UK the Soil Survey uses soil types, which are related to the mire types discussed above, but highly specific to local areas.

Koster & Favier (2005) give us four alternative main ways that mires are classified:

Ecological- based on nutrient content, plant communities or some other biological classification.

Geogenetic- based on the landforms the mire develops in, as outlined above- this is the basis of the scheme used for the lowlands in the UK

Hydrogenetic- based on a combination of position in the landscape, water input and peat forming processes related to it. There are 8 types, based on research in Germany.

Hydrogeomorphic- This scheme has a very long list of peat-bog types based on topography, water sources and formation processes. It is more descriptive than categorical.

As has been mentioned above, the Soil Survey of England and Wales, in their Gazette of lowland peat in England (Burton & Hodgson 1987) describe specific soils and layers using soil terminology and classifications, but they also have a classification scheme for mires, which is essentially the geogenetic scheme, with adaptations for the UK.

The Gazette is the main reference for lowland peat and mire locations in England, yet in archaeology a much simpler distinction is made, simply that between upland and lowland peat. In the MAREW report, this distinction was not explicit, but based on the schema used by the Soil Survey of England and Wales (Burton & Hodgson 1987) which has a cut-off between the two types at 200m OD; the soil survey only considered lowland peat, which excluded ombrogenous mires almost entirely. This is not as arbitrary as it seems, it is the rough height above sea level at which rainfall inputs will exceed outputs via run off, through flow and evapotranspiration, thus distinguishing between ombrogenous mires and the lowland types which tend to be topogenous. This simple binary distinction is used throughout the archaeological literature, but particularly by English Heritage in terms of research frameworks and

planning (Darvill 1987; Howard-Davis *et al.* 1998; Olivier & Van de Noort 2002; Van de Noort *et al.* 2002a; Webster 2004; Hodgson *et al.* 2005).

Finally, it is important to remember that though slow to change, peat environments are dynamic systems, changing over time and in response to external pressures (Dincauze 2000, 335). Mire types almost never occur in isolation; it is possible that one mire type might overlie another, or represent a vegetational climax, as in the case of raised bogs over old lacustrine systems. Furthermore, particularly in the lowlands, distinctions between lowland peat and other wetland systems and sediments are not always straightforward; there is likely to be a zone of interaction between the two types of deposit, with complex interleaving of sediments.

3.3 Peat formation processes and timescales

Peat development is closely tied to many of the classification schemes as, quite often, the environment that allowed the peat to start forming is the basis of the classification. Here we will examine typical succession sequences, without going into details of typology, which was covered in section 3.2, above. As already mentioned, it is very rare for peat types to occur in isolation. The only exceptions are blanket mires, which tend to be thin and form on upland slopes where the net water input exceeds the runoff and loss through evapotranspiration. In these mires a relatively thin layer of terrestrial peat forms. Sometimes, a raised mire forms over a blanket mire, depending on the slope of the site.

3.3.1. Peat formation processes

In order for peat to start to form, one key condition must occur. The water input into the immediate environment needs to be larger than the output. This can result either from rainfall only, as in ombrogenous bogs, or from a mixture of rainfall and throughflowing water, as in topogenous fens. Waterlogging slows down the decay of organic material, and as the oxygen level within the water is depleted by the limited decay process, decay of organic matter slows even further. The relationship is non-linear. If the oxygen levels are not replenished by diffusion (which is why fast flowing water systems tend not to form peat), the only decay processes left are anaerobic ones. This leads to very slow decay of organic matter, and once deposition rates outpace decay rates, peat will start to form from this accumulated matter.

Peat does not need open water to start to form; it can start to form in waterlogged soils as well. Key drivers in peat formation are the sphagnum mosses. This species of moss is ubiquitous in the 'raised bog' stage of peat development, and their dominance is key to bog formation (Koster & Favier 2005, 166) as they modify the ecosystem to make it more compatible for themselves and less so for other plants. The key to this is their ability to acidify the water around them through cation exchange, making the environment hostile to other plant species. Raised bogs are often therefore less species rich than fen systems, where sphagnum plays less of a role in the mire ecosystem.

Generally speaking, there are two main types of peat formation.

Peat growth may start in stagnant or slow flowing water, as organic sediments build up and gradually terrestrialize a lake or valley floor. This leads to a succession of peat types, starting with lacustrine, limnic peats or perhaps accumulations of dy, gyta, or lake marls, then telmatic peats as shallow water plants and swamp or reed bed vegetation moves in. Eventually, terrestrial peats will form. These might be woody fen peats at lower elevations and systems that are base rich or mineral rich, or at higher elevations or in more acidic, oligotrophic conditions, a raised bog might develop. It is also possible, given local conditions or shifts in climate, that a raised bog might succeed a fen mire and vice versa.

Alternatively, changes in climate or local topography might trigger a process of paludification, whereby a soil starts to receive more moisture than it sheds. Over time, telmatic and then terrestrial, or simply terrestrial peat may form as the vegetation changes in response to the shift in moisture regime (see Figure 3.2). This seems to have been the process by which much of the upland peat in great Britain was formed, due to climate changes in the Flandrian (Simmons 1996), and also partly due to human influences in the uplands in the Mesolithic and Neolithic, clearing trees and thus changing the hydrological conditions of the soils. The resulting mire types will largely depend on the climate and elevation the process occurs at. The inception stages and the deposits left behind will also be a function of this; in a forest you might get a horizon of preserved trees or tree stumps, in quite a woody peat layer, before the succession gives way to telmatic peats formed in the swamp and then terrestrial peats

as a raised bog forms. Over thin upland soils, with no forest present at the time of peat inception, there may be a pretty straightforward change to terrestrial peat in the form of a blanket mire, but with associated gleying of the underlying mineral soil due to the increased water throughputs that start the peat growing process.

Accumulation rates vary considerably. They can be as high as 5cm/ year in eutrophic lakes, but more typically 20-100cm per 1000 years (though values between 4 and 500 cm per 1000 years have been recorded (Koster & Favier 2005, 168). The accumulation rate generally decreases with age, and also depends on mire types, for example in fens, primary productivity is higher, but so are decay rates. Accumulation is not just about the height of the bog; as material is added to the top of the system in the acrotelm, the catotelm is compressed (Clymo 1983). This causes serious complications of interpretation for ecologists and archaeologists, because even if the accumulation rate is known or can be estimated, compression rates vary, so there is no simple correlation between depth and the passage of time since deposition. This can also compress and distort archaeological deposits, concatenating sequences and physically altering artefacts and structures.

3.3.2 Peat formation timescales

In the study region, all peat deposits have formed since the end of the last Devensian Ice Age and so belong in the Holocene. The Holocene has four climatic subdivisions (pollen zones V –IX) (Darvill 2002, QR4) which are more relevant to the formation of ombrotrophic peats (often started by climate shifts) than minerotrophic ones (that generally occur in association with rivers and coastal systems).

In the lowlands, peat formation commenced with the start of the Flandrian, largely by processes of terrestrialization in depressions in glacial till and in the newly forming valley systems of rivers. Changes in sea level and rainfall levels contributed, especially in coastal regions where hydrological systems were affected (i.e. slowed down or damned up) by eustatic and climatic sea level shifts. Extensive peat ecosystems formed in Northwest Europe (Koster & Favier 2005) by the time of the Neolithic, and continued to grow and evolve until heavy exploitation and drainage commenced during the Middle Ages.

In the uplands the system is more complex. Blanket bogs are rare in continental Europe but much more common in the UK and Ireland as they require a cool, humid oceanic climate. Upland raised bogs and blanket bogs cover a lot of the uplands of the UK, but this is not the 'natural' state of these uplands; in the early Flandrian, they were largely forested, to elevations that allowed tree growth. However, through a mixture of human activity (undisputed for the Neolithic, and tentatively identified in the Mesolithic in some areas (Simmons 1996; 2003) and shifts in climate during the second millennium BC towards wetter, cooler conditions and following the complex process shown in Figure 3.2, many of these areas became upland moors; extensive peatland environments. This process was ongoing throughout prehistory, and from the Iron Age onwards in the UK, seems to have kept human settlement activity away from these zones, at least until the Middle Ages (Van de Noort *et al.* 2002a).

3.4 Peat chemistry and physics

A surprisingly large number of people besides archaeologists are interested in peat environments. Engineers need to know how it behaves for construction projects, like oil pipelines (Jol & Smith 1995); ecologists need to examine the nutrient loadings and hydrology (Comas *et al.* 2004b) and they have been using geophysical means to investigate these environments for some time, principally GPR and ERT though with some seismic work as well (Theimer *et al.* 1994; Plets *et al.* 2007). There have also been studies looking specifically at the physical and chemical properties of peat, not using geophysical methods. A key synthesis often referred to by the engineering community was published in the *Quarterly Journal of Engineering Geology* in 1986 by Hobbs. It largely focuses on the compression properties of peat and modelling for shrinkage, though it contains pertinent chemical information as well. A slightly earlier synthesis by Clymo (1983) seems to be more favoured in the ecology community, as it follows a slightly different emphasis, focusing on organic and inorganic chemistry, accumulation and compression rates and peat ecology. Both are good syntheses of the information available at the time, and include what was then very current research. They are still cited in the literature frequently, but this is possibly due to a lack of more recent updated books or papers on the topic.

Discussions of peat physics seem primarily to be concerned with properties relevant to engineering problems, such as shrinkage and expansion, and more catastrophic

events like landslides and bog-bursts. The geophysical responses of peat have also been considered, primarily for mapping different peat types and understanding the landforms below peat. This might be to assess the ground ahead of a construction project, or perhaps to assess the commercial potential of the peat resource. There is also a growing interest in using peatland environments to sequester carbon dioxide to reduce atmospheric CO_2. These physical assessments also have relevance to archaeological geophysical prospection; poorly humified peats (fibrous peats) seem to have higher total water contents than well humified (amorphous) peats (Clymo 1983, 28). This difference could show as an anomaly in a geophysical survey, so an awareness of the different properties of different peat horizons within a site will clarify interpretations a great deal.

Peat chemistry is a vast research topic in its own right, with specialisations in understanding the acrotelm and catotelm (Lindsay 1995, 9). Clymo (1983) and Sikora & Keeny (1983) give an introductory account. The focus of these studies is usually ecological or hydrological, and is therefore concerned with aspects such as nitrogen cycling, peat as a carbon sink or peat as an indicator (and possible dispersal mechanism) for heavy metal pollution. The decay mechanisms within peat and the influence this has on stratigraphy and the differential survival of different types of organic material is well covered, as are the consequences of peat oxidation when it either dries out or is excavated for commercial reasons.

Some aspects of peat chemistry relate to the geophysical response to peat deposits; processes of magnetic enhancement (or the inhibition of this (Thompson & Oldfield 1986; Weston 2004)) and factors affecting conductivity and a related property, relative dielectric permittivity. As well as being governed by physical factors such as the porosity of soils, conductivity is also influenced by the presence of soluble salts (Essington 2003, 502). Indeed, one of the applications of electromagnetic survey outside of archaeology is in conductivity mapping for agriculture, as an indirect observation of salinity (Lesch *et al.* 2004, to give one example). In salt marshes, Kattenberg & Aalbersberg (2004) have examined the role of waterlogging and saline inundation on the inhibition of MS enhancement in archaeological features coupled with the creation of strongly ferrimagnetic natural deposits. It must be emphasised that the intent of the chemical investigations reported in Chapter 9 is not to try to

understand the whole of the complex chemical properties of the peat bog, but rather to examine those aspects which are likely to impact on the geophysical properties of the peat.

3.5 Peat distribution in Northwest Europe

Figure 3.3 shows the current distribution of peat in Northwest Europe. Peat formation is governed by rainfall and hydrology, as discussed above. Northwest Europe is climatically well-suited to the formation of large areas of peat, but surviving peatlands are reduced from their maximum, largely as a result of drainage and reclamation for agriculture and development. In Holland, around 2000 BP it is estimated that 35% of the country was peatland, and this has reduced to around 11% today (Koster & Favier, 2005, 163). This process started in the Middle Ages and is ongoing. Ireland, The Low Countries and Northern Germany retain particularly large areas of lowland peat deposits. Defining exactly what classes as a peat soil is complex, with disagreements between various schemes about the organic content, and how much clay the mineral fraction can have (Montanarella *et al.* 2006), meaning that quantifying and mapping peatlands is a complex task. The map presented in Figure 3.3 is the relative percentage of peat soil or peat-topped soil coverage for the Soil Mapping Units (SMUs) used in the European soil database.

Figure 3.4 shows the distribution of drift geology classified as 'peat' by the British Geological survey. It is the basis of the mapping used in the MAREW report (Van de Noort *et. al.* 2002), which is modified to include alluviated wetlands like the Lincolnshire silt-fens. The definition of a peat soil used in the UK is that it must be at least 40% organic, and 'decimetres' thick (Burton & Hodges 1987).

3.6 Threats to peatland environments

The threats to peat depend in part on the location of the deposits; in the UK, commercial peat extraction has more or less ceased but it continues in Ireland, Finland and some other areas. For lowland and upland raised mires, this had been the biggest threat of the last century, though this is reducing as alternatives in horticulture and agriculture are perfected. It is still used as fuel in some places, and so these environments remain under threat, but they also provide us with ongoing

opportunities for new discoveries, as long as any extraction operations are done with cooperation between archaeologists and the companies involved, as it was during the Somerset Levels Project (Coles & Coles 1986, 190).

A more insidious problem, particularly in the lowlands, is the drainage of peatlands. In many cases this was started in the middle ages, but as farming intensifies and practices change, it is increasingly a problem. Drainage causes rapid changes in the ecosystem of a bog, and has implications for any buried archaeological remains. As the range of the local water-table increases, the catotelm is reoxygentated and its preservation properties are rapidly lost (Hobbs 1986, 25). If this is accompanied by dry conditions, then peat may be lost from the top of the bog surface to wind erosion, particularly if it is under cultivation. For example, large areas of the East Anglian Fens have sunk some 4-5m since the mid 19th century, as evidenced by the Holme Fen Post (Godwin 1987, 27, 31). Drainage is not just for agriculture; development requires the consolidation and stabilisation of these environments to allow structures to be built. There is growing concern about the footprint of developments in peatland environments having effects far beyond the immediately affected area as changes to the hydraulic gradients within the peat occur.

This problem is compounded by the effects of climate change; increasingly dry summers are possibly contributing to erosion and drying in lowland environments. There are real fears in the ecological community that climate change could well be accelerated by the release of methane and stored CO_2 in these areas as the peat becomes oxygenated and starts to decay.

Threats are not restricted to the lowlands. As discussed above, the upland mires in the UK are distinctive environments, relatively common here but rare globally. They occur due to our unique oceanic climate. If significant shifts in rainfall patterns occur, it is possible that the conditions that sustain these ecosystems could cease to be maintained. Drier summers, combined with changes in agricultural policy (see below) also have a more immediately catastrophic affect in the form of fires. Dry peat is a fuel source, and if fire takes hold in a desiccated bog, the whole acrotelm, and possibly the catotelm can be lost. Once the acrotelm is gone, the catotelm is subject to further drying and wind and water erosion, so problems can continue long after the

fires are extinguished. One example of this sort of threat is the large fire that occurred on Fylingdales Moor, North Yorkshire in September 2003 (English Heritage 2003). This catastrophic fire exposed a whole landscape of features, from prehistoric field systems to Medieval alum mining. Whilst the fire allowed site prospection by aerial photography, fragile archaeological remains were at risk of damage and destruction until vegetation cover could be restored.

There are also threats from more direct human activity. Upland moors in the UK were artificially created and maintained landscapes; they rely, to some extent, on ongoing human exploitation in the form of hill farming to retain their character. As the nature of farming is changing, and incentives to manage these landscapes run dry in the light of the current economic climate, vegetational shifts are already being observed, and some of them are starting to affect the visibility of archaeological sites, for example on Dartmoor. Here, local landowners and community members have been trying to raise awareness of these problems (Dartmoor Preservation Association 2008; Paxman & Turner 2008; Rendell 2009). If the situation continues, the need for a prospection tool in these environments becomes all the more pressing, as invasive damage from bracken and gorse, and the loss of visibility of sites under molinia, take their toll.

Chapter 4: Peat and geophysical prospection

4.1 Introduction

This chapter deals with peat and geophysical prospection. As already mentioned above, geophysical surveys have been undertaken in peatland environments, though not many by archaeologists, or with archaeological targets in mind. This chapter will examine briefly archaeological geophysics as sub-discipline of near-surface geophysical prospection, and assumptions within that speciality about the utility of prospecting in peat. Then, archaeological surveys that have been carried out on peatland will be examined to see if any conclusions can be drawn about prospection guidelines Non archaeological applications of geophysical survey in these environments will also be examined. A final section looks at some very recent developments in archaeological applications, and considers data processing and validation methods briefly. The specifics of the selected geophysical techniques and of data processing and validation are discussed in detail in Section 2, Chapters 5 and 6.

4.2 Archaeogeophysics

Gaffney and Gater define archaeological geophysical survey as '*The examination of the Earth's physical properties using non-intrusive ground survey techniques to reveal buried archaeological sites, features and landscapes*' (2003, 12). The authors go on to acknowledge that they have excluded aerial and satellite remote sensing, soil chemistry, and marine geophysics from this definition. These subjects are also classed as geophysics, or as archaeological prospection, but they are not of further interest to this piece of research. At best, they can be used to locate peatlands (Cox 1992; Ruffell 2002), but given the problems already hinted at with aerial site prospection in these environments, only ground-based techniques will be given further consideration.

There have been recent revisions to the history of archaeological geophysics (Bevan 2000a; Hesse 2000), citing early examples in France and the USA, but it remains widely acknowledged that the UK is where the discipline is most mature, and where more archaeological geophysics takes place than anywhere else in the world (Gaffney & Gater 2003, 13, 22; Johnson 2006a, 9-10). In 2003, Gaffney & Gater acknowledged that the discipline in the UK had moved from being research led to a commercial

footing, but cautioned that this has possibly led to a degree of stagnation in terms of techniques. Established practice is possibly perpetuating decisions about optimum surveying techniques that were constrained by data processing, display, and storage considerations of twenty years ago. Encouragingly, recent work from North America has suggested a reconsideration of some basic principles of resistivity survey, for example (Bevan 2000b). Whilst this 'established' nature of the discipline in the UK is not without problems, it also means there are a number of advantages in basing the case studies here; there are a large number of completed surveys (even if not all are published), and the sometimes paradoxical responses of our soils are reasonably well understood (Gater 1981; Clark 1996, 48-53). Archaeological geophysics typically makes use of the following techniques; magnetometry (in the form of total field or gradient measurements), resistivity (both as area surveys and as Electrical Resistance Tomography (ERT)), GPR, and electromagnetic surveys (which may examine magnetic susceptibility, electrical conductivity or both). Less frequently, and usually in response to specific issues or environments, gravimetric, seismic and induced polarisation surveys might be employed (Gaffney & Gater 1993; Clark 1996; Gaffney & Gater 2003; Johnson 2006b).

Given the current state of the discipline, four 'conventional' techniques were tested in a range of environments to fulfil the aims and objectives of this piece of research. They were selected as they are more routinely used in archaeological prospection, and therefore familiar and available to those working in the field who wish to put these findings into practice. It was never within the scope of this project to develop new prospection methods or engage in methodological innovation. Techniques were therefore needed that had 'settled' in terms of our understanding of them, and where their strengths and weaknesses were well known. Thus, twin probe resistivity, gradiometry, ground penetrating radar and frequency domain electromagnetic prospection were selected for evaluation.

4.3 Assumptions about peat

Assumptions are made about the deposit being too deep (David 1995, 12), too magnetically blank (David 1995, 12; Clark 1996, 92; Clarke *et al.* 1999b, 110) or too wet (David 1995, 12; Clarke *et al.* 1999b, 108; Gaffney & Gater 2003, 52), but these assertions have never been fully tested. English Heritage (2008, 16-17) recognises the need for further exploration, and specifically ground-truthing where techniques have

claimed to succeed. The ground-truthing of claims made from GPR, for example, is limited at best and very little research into the response of conventional techniques has been done beyond the initial surveys at sites like Fiskerton (Martin 2002) and Flag Fen (G S B Prospection 1999) and The Sweet Track (Utsi Electronics, 2001). Explanations for success and failure have rarely been sought.

Peatland archaeology, so by inclusion peatland geophysics, has a different character than the majority of archaeology practiced in Northwest Europe. Geophysical survey on dry sites is normally characterised by a desire to detect features cut into or upstanding from a previous ground surface, through a (hopefully) shallow overburden of ploughsoil or other cover deposit. This overburden is viewed as a noisy barrier to be filtered out to get to the features beneath.

In upland peat environments, where the peat is shallow, the basic principles are the same; the aim is to locate the buried ground surface and any cut or upstanding features. Problems for the survey are caused by the very wet nature of the soils and the low magnetic enhancement capacity of waterlogged soils, coupled with the likelihood of thermoremnant 'noise' caused by the (usually) igneous underlying parent rock (David 1995, 10; Clark 1996, 92-5; Gaffney & Gater 2003, 37, 79).

In lowland environments, and in some upland environments where the peat has formed a raised bog, or very thick blanket bogs, then the situation is more complex. There is a deep stratigraphy of peat, more than 8m in some environments (Burton & Hodgson 1987; Lindsay 1995). It is possible to have archaeological targets at varying levels within the peat matrix, such as trackways and platforms built on stable 'horizons' within the peat, features from the pre-peat landscape, as well as the complex morphology and stratigraphy of the peat itself, particularly where there is interaction with alluvial systems, leading to interleaved deposits. Rather than a two dimensional plan of cut and raised features (see Figure 4.1), we have a three dimensional system of interleaved layers with features distributed throughout, and sometimes vertically between them (see Figure 4.2).

The issues outlined above cause a number of problems for the geophysicist. The sheer depth of the deposits is a major obstacle. Most geophysical survey in the UK is aimed

at targets buried under less than 1m of overburden (David 1995, 11; Weston 2001, 266). As such, instrumentation, survey procedures, and data processing routines are geared up towards this depth, and tend to treat the overburden as something to be filtered out. In peat environments (as with some other complex environments, (Weston 2001; Carey *et al.* 2006; Watters 2006; Conyers *et al.* 2008)), archaeological targets may be located at multiple levels within the covering deposits, and may overlie or underlie other features. Instruments capable of making depth assessments are needed, and ways of interpreting the data in three dimensions are required to make sense of it all. The nature of the deposits themselves also makes survey difficult. They are wet and they are not readily magnetically enhanced (Thompson & Oldfield 1986, 81-2; Weston 2004). Contrasts, in physical and chemical terms, between the waterlogged archaeology (where the targets are wooden structures, for example), and the waterlogged peat are very low, potentially outside the limits of detection for current equipment, even where it has been specifically developed with this purpose in mind (Weller *et al.* 2006, 123).

4.4 The existing body of surveys in the UK

Searching for previously completed geophysical surveys is a complicated matter. Many are never published and remain as grey literature, existing as contractor's reports in local SMRs or as unpublished student dissertations. It is beyond the scope of this research project to try track down, record and summarise every geophysical survey undertaken on peat soils in the UK.

A literature search reveals surprisingly few ground-based geophysical surveys over UK peat bogs, perhaps due to the fact that results in these environments are frequently (as I will show below) less than conclusive, so rarely make 'good' papers for journals and conferences. Notable exceptions are the work done at Ballachulish Moss (Clarke *et al.* 1999a; Utsi 2004), work on a trackway at Parks of Garden and other Scottish wetland sites (Utsi 2003), MS methods trialled in the East Anglian Fens (Challands 2003), and the wealth of information about surveys in the Orkney World Heritage Site. In many published accounts, it can be difficult to pin down exactly what the drift geology is on the site under discussion, unless it is made explicit in the title of the paper. Identification of peatland environments by remote sensing has also been

covered in the literature (Cox 1992; Ruffell 2002; Challis & Howard 2006; Challis *et al.* 2008).

There are no published papers concerned with non-archaeological geophysical prospection in peat in UK though there are papers concerning the identification of submerged peat deposits in marine geophysical data (Plets *et al.* 2007). Discussions with practitioners indicate that near surface surveys in these environments have been employed in forensic contexts in the UK, searching for clandestine grave sites and potential weapons caches, though the results of these surveys do not make it into the published literature due to legal constraints. They also seem to have met with little success to date (pers. comm. Donnelly 2008).

The grey literature is held by Historical Environment Record offices, English Heritage and their counterparts in the rest of the country, universities, commercial units, and the records of amateur societies. Searching this huge resource was beyond the scope of this project, but in recent years the problem of grey literature in archaeology has been in the foreground, and some efforts have been made to catalogue this vast array of data (Richards 1997; Darvill & Russell 2002; Richards 2002). English Heritage make available a database of all surveys carried out by their geophysical survey team, and their antecedents, the Ancient Monuments Laboratory, from 1972 to the present (Linford, P 2004). It also has some other surveys voluntarily reported by other surveyors from 1996 onwards. There is also a physical library of Ancient Monuments Laboratory, and later the Archaeological Science Team, reports on (amongst their other activities) geophysical surveys. A search of both sources was conducted, and combined with a search of the Archaeological Investigations Project (AIP) database (Bournemouth University 2009). The AIP is based at Bournemouth University, and aims to catalogue all archaeological investigations, from desk based assessments to excavations carried out from 1990 onwards. This includes geophysical survey. The project was specifically commissioned by English Heritage to record information in a searchable format from all of the grey literature that exists, mainly as 'client reports' produced by commercial archaeologists. The project visits all archaeological units and trusts, and aims to visit all SMR/HER offices as well, and also records information voluntarily provided by local societies.

Both of these resources cover England, and similar projects exist in Wales, Scotland and Ireland but the information is not as inherently searchable by the soil type and geology. As such, the following discussion is based on sites recorded by either the AIP or by English Heritage, or 'grey' reports provided by local HER officers in the regions case studies were planned, during the initial phases of the research project, that did not already appear in the data obtained from the AIP or EH (GSB Prospection 1999; Utsi Electronics 2001; Dean 2003; Johnston & Wickstead 2005, Quartermaine 2007). It is likely that there are similar surveys recorded elsewhere in the UK, especially considering the comparative amount of peatland environments in these regions compared to England. Unfortunately, it was not practical to try to inventory the surveys in these regions.

As Table 1 shows, there were 59 surveys *recorded* where peat was mentioned in the soil or geological description of the site between 1972 and 2007. This means some surveys have been included which were only partially over peat soils. This is unlikely to be all of the surveys *conducted*, but it gives a decent representation of the types of survey that have been attempted, and the results they obtained. The information in the table is very basic, but that is because for some surveys there were full reports available, other records just stated a survey had taken place, and what techniques were employed. The data presented is the best fit between the two extremes, and gives some idea of whether features were detected and the depth of information able to be gleaned from the surveys. Where the surveys were part of a wider project, is has been hard to distinguish which features were specifically located by geophysical means; this uncertainty is clearly indicated in the database and Table. The locations of the surveys (to a minimum accuracy of a six-figure grid reference) is shown in Figure 4.3, which also shows peat soils as recorded in the 1: 625,000 scale drift geology map of the UK, produced by the British Geological Survey, and the boundaries of all UK Ramsar wetlands, to contextualise the survey sites.

There are distinct clusters that form in areas where there have been extensive wetland archaeology research projects, such as South Yorkshire and the Humber region, the East Anglian Fens, Lincolnshire, and the Somerset Levels. There are also smaller groups on Dartmoor, in Cumbria and in Greater Manchester. The Dartmoor sites and the site on Hadrian's Wall (27) are upland sites, and Oxford Archaeology conducted

research surveys at Barnscar (59) but the picture is otherwise dominated by lowland peat environments.

Figure 4.4 shows summary information about the surveys conducted. As can be seen, the majority of the sites were surveyed with only one technique, with only ten sites being subject to the same areas being covered by different survey types. The majority of those surveys were carried out by fluxgate gradiometer, or other magnetic means. This is perhaps unsurprising given the role of the fluxgate gradiometer as 'the workhorse of British geophysics' (Cheetham 2005, 77; English Heritage 2008, 21), but a little concerning given that the inhibition of anthropogenic magnetic enhancement of soils has been documented since the mid 1980s (Thompson & Oldfield 1986; Clark 1996, 69). It possibly relates to the advice in the English Heritage guidelines (David 1995) to use magnetometry and resistivity at the margins of peat deposits, in order to infer the continuation of features into the 'un-prospectable' peat, especially bearing in mind that many of the entries in the table probably reflect sites only partially based on peat soils.

There are 7 recorded GPR surveys, but 4 were conducted in isolation, presumably in landscapes (such urban areas (25) or within buildings (42)) where other techniques were unsuitable. There seems to be a contrast between the development-lead surveys, which tend to be single technique, and research-lead, using multiple methods, such as the work at Fiskerton by the EH the Geophysics Team.

The dates show that surveys occurred only sporadically up to 1989 but from then on there is at least one, and often more, geophysical survey recorded each year, reaching a height in the mid 1990s. This is linked to both the wider use of geophysical survey in archaeology as the technology has stabilised, but also the introduction of PPG16, both of which subjects are admirably covered elsewhere (Darvill & Russell 2002; Gaffney & Gater 2003, for the basics). The predominance of magnetic techniques makes inferring change over time quite difficult. It is hard to say whether the apparent pattern of more research-type survey and more resistivity survey in the earlier part of the period result from biases in the data collection, or are real reflections of practice. Certainly, the comparative explosion of the use of geophysical survey in commercial archaeology following PPG16 (and which has been discussed elsewhere, for example

Darvill and Russell; 2002, Gaffney and Gater, 2003), can be seen in the data in the form of increased survey numbers after 1989 and the predominance of fluxgate gradiometry.

From the data available, it is was difficult to tell (except where full reports were provided by the Fort Cumberland library) exactly how successful the surveys had been in terms of detecting archaeological features and meeting the survey objectives. Nonetheless, the data does show that in more than half of the cases some features of archaeological interest were detected. Without the level of detail afforded by access to the full reports, it not possible to state whether these detections were deemed a 'success'. Certainly in an examination of the full reports that were available, successes were mixed. Surveys at Fiskerton, for example, seemed to have produced very little in the way of archaeological features, revealing only modern field drains and some ambiguous anomalies that proved impossible to interpret (Martin 2002). In contrast to this, surveys at the Sweet Track (Utsi Electronics 2001) and on Dartmoor (Dean 2003; Johnston & Wickstead 2005) have successfully located anomalies related to prehistoric monuments. There is a disparity between these records and the pessimism in the current UK guidelines regarding survey in these environments (English Heritage 2008, 16-17). Reading between the lines of both the data gathered here, and the survey guidelines, it seems that the problem is not that surveys in these areas produce entirely negative results, more that the results are unpredictable and challenging to interpret. English Heritage are therefore correct (2008, 17) when they call for more rigorous testing of techniques and ground-truthing of surveys in these environments, with a key aim to be resolving these ambiguities of interpretation as far as possible.

Table 1: Peatland Archaeological Geophysical Surveys in the UK

Number	Site Name	Date	Methods	Features
1	SEAMER CARR 1	1976	FG	ND
2	SEAMER CARR 2	1977	FG	Features? (Unconfirmed by augering), Ditch, Undated
3	MEARE LAKE VILLAGE 1	1978	FG, (MS)	?Hearth, Iron Age
4	HADRIANS WALL MILITARY WAY	1981	R	Road, Ditch, Vallum, Roman
5	MEARE LAKE VILLAGE 2	1984	FG	ND
6	TINTAGEL CASTLE	1988	TP, FG, (MS)	Geological
7	CHURCH STREET, MILBORNE PORT	1989	MD	ND
8	WORGRET HEATH	1990	M	Drainage Ditches, (Flint) Undated
9	PAVE LANE, CHETWYND ASTON, NEAR NEWPORT	1990	M	Enclosure, Ditches, Undated
10	KILLERBY CARR, CAYTON	1991	R	(Flint) Undated
11	A140, SCOLE DICKLEBURGH IMPROVEMENT (RIVER WAVENEY TO A140 SOUTH)	1992	MD	(Field boundaries, ditches, cremation, features, marching camp, sites, roads, town) Roman, Medieval, Modern & Undated
12	LANGTOFT COMMON, LANGTOFT	1992	M	Saltern, Iron Age
13	FEN DRAYTON	1992	FG, MS	ND
14	ROTHERHAM TO STOCKSBRIDGE OXYGEN PIPELINE	1992	FG (SCAN)	Features, Field Boundary, Undated
15	THE AI43 SCOLE TO STUSTON BYPASS PREFERRED ROUTE-PHASE II	1993	MD	(Post Holes, Hut, Flints, Drains, Pit, Quarry, Road, Settlement; Neolithic to Medieval)
16	ISLEHAM TO ELY PIPELINE	1993	M	(Finds), Neolithic, Bronze Age. Settlement/Beehive Pit, Iron Age. Ponds, Ditches, Pits, Burial, Postholes, Undated. Pits, Barrows, BA. (Finds), Post-Med
17	BLOCK FEN B, PEARSON'S LAND, MEPAL	1994	R, M	
18	MILDENHALL RELIEF ROAD HOLYWELL ROW ANGLO SAXON CEMETERY, MILDENHALL	1994	MD	(Ditches, Features), Medieval. (Grave, Inhumation, Cemetery), Anglo Saxon. (Pit), Undated
19	HIGH STREET, HECKINGTON	1994	M	Ditch, Undated
20	PROPOSED TIDAL DEFENCES AT SALT END	1995	M	ND
21	BASTON DROVE, LINCS	1995	FG (MS)	Geological/Pedological, Misinterpreted from FG survey as
22	SWEET TRACK, SOMERSET LEVELS	1995	GPR- 300 & 120 MHz	Trackway, Neolithic
23	BARLEYCROFT FARM, CAMBS	1995	FG	Features, Undated
24	PINCHBECK	1995	MS	ND
25	ELY CENTRAL AREA DEVELOPMENT	1996	GPR	Rubbish Pit, ?Oven, Medieval & post Medieval. Building Floor, Posthole, (Finds), Post Medieval. Posthole, Undated.
26	MEARE LAKE VILLAGES 1	1996	TP, FG, MS	Mounds, Iron Age. Excavation Trench, Stakes, Modern
27	GALEWOOD HOUSE, NEAR MILLFIELD	1996	FG, R	Features, Modern
28	LATHOM HOUSE	1996	FG, TP	?Garden Feature, ?Wall, Undated. Features, Modern
29	BLUE CIRCLE SPORTS GROUND COMPLEX, NORTHFLEET RISE, EBBSFLEET	1997	R	None logged
30	DECOY FARM, HOCKWOLD CUM WILTON	1997	MD	(Finds), Mesolithic, Neolithic, Early Bronze Age, Bronze Age, Early Medieval, Medieval
31	BLACKRIGG FARM AND MOSSBAND HALL FARM, CARLISLE	1997	SMD	Finds, Modern
32	MEARE VILLAGES	1997	TP, FG, MS	Mounds, Ditch, Iron Age. Excavation Trenches, Modern
33	WOODHOUSE LANE, HATFIELD	1998	M	Feature, Undated
34	BEACON HILL CAMP	1998	TP	Earthworks, Undated. Enclosure, Structure, Features, WWII
35	BUTTERBUMP BARROWS	1999	M	Barrows, BA.
36	BASING HOUSE II	1999	TP	Topography. Road, Services, Modern. Features, Road, Medieval and Post Medieval
37	TRANSCO - WEST HULL REINFORCEMENT PHASE II	2000	M	(Finds), Prehistoric, Roman, Medieval, Post Medieval. Ridge & Furrow, Feature, Ditch, Undated
38	EAVES GREEN LINK ROAD, CHORLEY	2000	M	Road, Field drain, Building, Colliery, Engine, Lodge, Shaft, Mill, Adit (Finds) Post Medieval. Feature, Mound, Modern.
39	FAR INGS, BARTON UPON HUMBER	2000	M	ND
40	THE SWEET TRACK AT CANADA FARM (UTSI)	2001	GPR- 400MHz	?Trackway, Neolithic
41	NORTHBROOK FARM, SHAPWICK	2002	CM	Villa, Roman
42	FISKERTON 1	2002	FG (MS), TP	Geomorphology. Pits, Ditches, Undated. Field Drains, Modern
43	WISBECH, ST. PETER AND ST. PAULS CHURCH	2003	GPR	Vault, Cellar, Burial, Undated
44	FISKERTON 2	2003	GPR- 450 & 225 MHz	Field Drains, Modern. ?Trackway, Iron Age
45	SUTTON COMMON ENCLOSURES	2003	FG	Ditches, ?Features, Iron Age. Paleochannel. Former Excavations, Modern
46	LANGSTONE MOOR STONE CIRCLE	2003	FG	?Stone Sockets, Prehistoric. Shrapnel, Ordnance, Modern
47	SHOVEL DOWN AND KES TOR	2004	FG, TP	Features, ?Kiln, Houses, Boundaries, ?Hearths, ?Pits,
48	NEWINGTON QUARRY	2005	FG	Pit, Linear Feature, Undated
49	EDEN GOLF COURSE, CROSBY-ON-EDEN, CARLISLE	2005	SMD	Finds, Medieval, Post Medieval & Modern
50	DONCASTER MOTOR TRAINING CENTRE, RANDS LANE, ARMTHORPE	2005	FG	ND
51	RIVER IDLE WASHLANDS, BAWTRY	2006	FG	Features, Modern & Undated
52	LAND AT OLD MILL FIELD, HATFIELD	2006	FG	Feature, Undated
53	STILTON	2006	GPR, FG	Ditch, Kiln, Pit, Undated
54	THE PROPOSED BOURNE TO GUTHRAM WATER MAIN	2007	FG	Modern/Undated, ND
55	STARR CARR FARM, HAXEY	2007	FG	ND
56	LAND EAST OF WELNEY	2007	FG	ND
57	LAND AT HILGAY, NEAR DOWNHAM MARKET	2007	FG	Linear features, Undated
58	FLAG FEN, TIME TEAM	1999	FG, R, CM	Pit, Ditch? Feature?, Undated
59	BARNSCAR	2005	GPR, R	cairns, stone banks, undated

Key: CM- caesium magnetometer, FG- fluxgate gradiometry, GPR- ground penetrating radar, M- magnetometry (unspecified), MD, metal detector, MS- magnetic susceptibility, (MS)- laboratory MS tests, ND- not disclosed, R- resistivity, unspecified, SMD- systematic metal detection, TP- twin probe resistivity.

4.5 Non-archaeological geophysical surveys of peat

As discussed above, there is a history of the use of geophysical prospection in peat for non-archaeological purposes. There are also potential parallels from marine and freshwater geophysical surveys as they too deal with organic archaeological remains (in the case of wooden wrecks) in waterlogged sediments.

4.5.1 Environmental and geological geophysical surveys

The extensive peatlands of Ireland, Scandinavia and Canada are an important natural resource, an important carbon sink and an engineering challenge. Geophysical survey has been employed for a long time in these environments to map and characterise them. As discussed above, surveys have generally been aimed at quantifying the peat resource (Hodgson *et al.* 2009), understanding the shape of the original landform (Comas *et al.* 2004a), and mapping different peat types for commercial and ground-engineering reasons (Jol & Smith 1995). Surveys are usually undertaken using GPR and ERT, along with soundings or cores to ground-truth the interpretations (Slater & Reeve 2002). These techniques have been shown to be reasonably reliable for their intended purpose and there has been some associated research on the interactions between the electrical characteristics of peat and the radar response (Theimer *et al.* 1994). Generally speaking, these types of surveys are conducted on the wrong scale to locate archaeological material; reading intervals or frequencies tend to be too low resolution to accurately map archaeological deposits but there has been at least one incidence of these surveys locating wooden timbers, during commercial surveys for Bord na Mona in the Irish Midlands, as reported in Hodgson (2009, figure 8).

4.5.2 Underwater archaeological geophysics

Some research has been undertaken on the geophysical responses of shipwrecks (Quinn *et al.* 1997; Arnott *et al.* 2005). Both reported studies used sonar, a technique only suitable for use in water, but it is worth drawing parallels to peatland geophysics, especially where the detection of waterlogged wood is concerned. Quinn *et al.* showed that shipwrecks could be successfully imaged with sonar, while Arnott *et al* noted that degraded timbers showed little response, and so had little chance of being detected against the sea floor, but intact timbers showed a stronger response. If this acoustically reflecting property translates into an ability to reflect radar waves, in

contrast to the surrounding peat, then this distinction in decayed/intact responses is important to note.

4.6 Recent advances in the application of geophysics to archaeological targets in peatland

In the last ten years, there has been some effort to make geophysical survey work in peatland environments, with various approaches being adopted. Some researchers have looked at conventional approaches, with only limited success. Others have considered new ways of using established techniques, and one research group has developed a specific tool to detect waterlogged wood remains in peat. All three of these approaches are considered in the sections that follow.

4.6.1 Conventional approaches

Conventional approaches comprise resistivity and magnetometry (Gater 1981; G S B Prospection 1999; Martin 2002; Dean 2003; Johnston & Wickstead 2005), particularly in the uplands where they seem to have enjoyed higher success rates. The higher degree of success in the uplands is likely to be due to the identified differences in both the character of the peat and the character of the archaeological targets. In lowland peat (for example the surveys at Fiskerton which did not reveal any archaeological features (Martin 2002)), the conclusions seems to have been the same as that of the EH guidelines; to the majority of techniques, organic features and deeply buried features of any kind are undetectable in deep peat, and so the best contribution to be made by geophysics is at the margins of the peat, prospecting for features which were placed on a buried land surface, and continue under the base of the peat (English Heritage 2008, 17). There has been some reported success in using borehole techniques to assess previous land surfaces under peat (Challands 2003) at sites in the East Anglian Fens. There are a large number of unpublished sites that exist as 'grey literature', explored in Section 4.4 above. As discussed, records of those surveys are often just summary information, with no detail about exactly which techniques detected which features or anomalies. It does demonstrate that in common practice, conventional techniques, particularly gradiometry, are being employed to prospect in these environments, and presumably with some success, or the practice would not be continuing.

4.6.2 New approaches

GPR is not as yet an established geophysical technique for most archaeologists, and indeed for many archaeological geophysicists (Conyers 2004). However, recent developments in memory capacity and processing capacity have made it a highly effective three dimensional geophysical tool (Gaffney & Gater 2003, 74; Leckebusch 2003; Conyers 2006b). Following successful surveys over peat by geologists to explore peat basin morphology, (Volkel *et al.* 2001; Leopold & Volkel 2003) a few researchers have trialled GPR in wetlands, usually prospecting for prehistoric wooden trackways known to lie beneath the peat (Utsi 2003), but in one case (Clarke *et al.* 1999b) as a 'blind' survey over Ballachulish Moss, a bog near Fort William, Scotland which had produced finds, but where no structures had been located by excavation. Another group of GPR surveys was undertaken as a research exercise aimed at better understanding and management of upland peat resources (Quartermaine *et al.* 2007) in Yorkshire and Cumbria. Varying degrees of success are claimed for these surveys. Utsi claims to have located trackways in Scottish bogs (Utsi 2003) and the Sweet Track in Somerset (Utsi Electronics 2001), and Clarke located platforms in Ballachulish Moss, as well as being able to describe the shape of the peat basin for the first time (Clarke *et al.* 1999b; Utsi 2004). On close reading, the work in Somerset Levels had problems with the lateral resolution of the position of the trackway. It is possible that they were in fact detecting the peat horizon the track was built on (Coles & Orme 1976a), rather than the trackway itself. Trial excavations found brushwood and sand/gravel platforms in the same location as one of the anomalies in Ballachulish Moss, but it is possible that the response was due to the presence of gravel within the platform, and not the wood itself (Clarke *et al.* 1999b, 117).

4.6.3 Tailored approaches

By way of contrast, one team of researchers based largely at Goethe University in Germany has considered the *geophysical* problem; how do you detect waterlogged wood when it is within a waterlogged organic matrix? They have developed a 'new' technique, Spectral Induced Polarisation (SIP). SIP exploits induced potential survey (where currents are created in the ground, and the properties of them measured), but uses an alternating current and looks at the response over varying frequencies and decay times (Kearey *et al.* 2002). This method exploits one way wet wood is different to wet peat; the waterlogged cells act as a polarizing membrane (Schleifer *et al.* 2002).

They report several successful surveys over trackways in German bogs, but a review of the work (Weller *et al.* 2006) cautioned that at the moment, the fine differences in SIP that were being detected were at the limits of the equipment currently available, and that with time better resolution should be possible. This is however a particularly specific solution to a problem and only really useful for detecting quantities of wood laid down in an organised manner. Furthermore, the development of novel techniques and equipment are outside the scope of this research.

What both the GPR and SIP surveys do demonstrate is that there are detectable differences between waterlogged wood and the surrounding peat matrix. Furthermore, results from conventional surveys in the uplands have shown that wet wood is not the only archaeological target in these environments, and so geophysical survey can definitely make a contribution where there are inorganic features to detect, such as the remains of hut circles or other buried stone, such as boundary walls, stone rows and stone circles (Dean 2003; Johnston & Wickstead 2005). Research by marine geophysicists has demonstrated that waterlogged wood has a characteristic response to sonar, which may be a useful parallel to explore (Quinn *et al.* 1997; Arnott *et al.* 2005).

4.7 Data processing and integration

Data processing techniques are a factor. For GPR and ERT the data processing methodologies are still being debated, in particular the mathematics involved in some of the complex spatial transformations applied to the data, (Mauriello *et al.* 1998; Leckebusch 2001; 2007) while for the other techniques used, novel approaches to data processing may be necessary to tease out the fine distinctions between the archaeology and its surrounding matrix. As has been pointed out above, the data is three dimensional so some of the data needs to be processed and visualised in a way that takes this into account. There is a distinction here between processing techniques such as the inversion of 3D blocks of resistivity data, or the timeslicing of GPR data, (Loke 2000; Leckebusch 2003; Booth *et al.* 2008) and visualising that data for presentation and interpretation, as fence diagrams, cut-aways or isosurface models (Leckebusch 2000; Kvamme 2006; Watters 2006). There is also a need to make comparisons between the results of highly differing techniques that respond to different properties of the ground. Qualitative comparisons are based on knowledge of the archaeology and the sediments, but quantitative comparisons would also be useful.

This is an area of debate at the moment, with no preferred or generally accepted methodology (Piro *et al.* 2000; Kvamme 2006).

4.8 Validation

Ground-truthing is an important aspect of the research; as has previously been stated, earlier work in peatland environments has been criticised for not providing this, and there is a more general call from the discipline for greater testing of geophysical results against excavation data and other verification methods. For example, of all of the geophysical surveys reported as having located waterlogged wood in the UK, only one has been verified by excavations, at Ballachulish Moss (Clarke *et al.* 1999a). The surveys there did successfully locate a platform in the bog, but the materials used to construct the platform included sand and gravel, so the detection of wood was not fully proven. Without ground-truthing surveys, the same untested interpretations of anomalies will be perpetuated in the discipline, possibly leading to gross errors that cause real damage, either to an archaeological site, or to the reputation of archaeological geophysics in the wider archaeological community.

An important to aspect of the ground-truthing work is the ability to explain the degree of success or failure; these explanations are what is missing from the current literature. By understanding what conditions of deposition and preservation allow detection by geophysical means, it will be easier to discern which sites would respond well to geophysical prospection methods. As discussed in Chapter 3, the chemical and physical properties of peat are not fully understood, so our aim has not been to arrive at causal explanations. Instead, focused physical and chemical tests of soil and water samples from the case study sites formed an integrated part of the ground-truthing work, tailored to specific issues raised at four of the case study locations. These ranged from macro level identification of sediments through to testing the peat composition with loss on ignition, laboratory MS measurements (Dalan & Banerjee 1998b; Marmet *et al.* 1999; Crowther 2003), and on one site, chemical analyses to look for patterns related to unexpected geophysical survey results. This followed standard practice for elemental analysis in soils and sediments (Aston *et al.* 1998; Bindler 2006), and was not aimed at exposing causative mechanisms, but at differential distribution of elements within the peat that may have an influence on the survey methods employed.

Peatland environments are very sensitive ecologically, so excavations may not be possible if the site is protected for environmental reasons; alternatives might need to be sought. Any below the ground intervention also risks damaging the archaeology with the introduction of oxygen and micro-organisms. The risks and benefits of any ground truthing strategy must be carefully weighed against these points.

At four of the case-study sites, a mixture of excavation, coring and laboratory tests on bulk and in-situ samples were used to interrogate the interpretations of the geophysical surveys. The survey data was then re-interpreted in the light of the ground-truthing work. This was an iterative process during the research project, with work at earlier sites naturally informing practice later in the study period.

Section Two: Data Collection Methodologies

This section consists of two chapters dealing with the overall methodology of the practical aspects of the research project.

Chapter 5 examines the ways peat environments have been classified by the various specialist disciplines interested in them, develops a heuristic typology of peatland types and expected archaeological site-types, and goes on to examine the reasons for selecting each of the case study regions and specific sites.

Chapter 6 explores physical principles, limitations and strengths of each of the four geophysical techniques selected for the project; resistivity, magnetometry, Frequency Domain Electromagnetic (FDE) and GPR.

Chapter 5: Classifications and case- study selections

This Chapter deals with the reasoning behind adopting a case-study based approach, then goes on to look at how the case study sites were selected through the development of a heuristic classification scheme for peatland environments and their likely archaeology. It concludes with a short statement about the overall methodological approach of the project.

5.1 The case study based approach

Early in this research a case study based approach was adopted, rather than testing techniques in the laboratory. The aim of the project is to evaluate the use of widely available geophysical techniques in peatland environments, in an archaeological context. Whilst testing techniques on real sites leaves many variables either uncontrolled or simply unknown, this is the situation archaeological geophysicists face on a day to day basis. It would have been possible to simplify and approximate these environments in the laboratory and then forward model the properties of soils and targets of known physical and chemical properties, and evaluate the techniques based on those responses. However, in reality peatland environments are complex dynamic systems. Any laboratory based assessments would have been starting places at best and simply inaccurate at worst. By selecting case study sites that look at a representative sample of peatland environments and archaeological targets, and identifying archaeologically useful questions about those sites that geophysical survey might be reasonably employed to answer, we can assess these techniques in a more useful and meaningful way.

In order to properly select case studies, a heuristic typology of sites was developed combining the type of peat encountered with the type of archaeology expected, to ensure selected sites covered the various permutations expected in the record.

5.2 Development of the classification scheme

The first step in developing the classification scheme outlined in section 5.2.4 was to examine existing classifications for peat used by archaeologists, ecologists, soil scientists, engineers and those with a commercial interest. As has been noted by Haslam (2003, 57-103), classification schemes for peat are many and almost infinitely

varied, and normally depend on the use they will be put to, rather than any underlying absolute distinctions in the peat itself.

There is a distinction between the classification of peatland environments, and the peat deposits themselves. The two are inextricably linked, as the peat deposits are the remains of the plant community of the mire, but they may be different at different stages of the mire growth. We therefore need to consider both types.

5.2.1. Classifying mires

What follows summarises Koster & Favier (2005, 168-70). Ecological classification schemes are usually concerned with two things; the current state of the mire or fen ecosystem, and the 'natural' state of that ecosystem in primary (i.e. unmodified) bogs and fens, of which there are sadly few. Thus the schemes tend to base classifications on ecological drivers, such as the nutrient status of the water involved in the maintenance of the waterlogged environment, or the elevation which influences which species will be able to survive. Of course, the 'climax' ecosystem of a peat environment is likely to be a product of a number of factors which will involve the way in which the system has developed, so they will also in part classify the peat deposits themselves. A variety of classification schemes are discussed in brief, below, to illustrate the different approaches sub-disciplines have and the complexity within the literature.

Hydro/geological classifications schemes cross into ecological schemes as they tend to focus on a combination of the water sources and the underlying landforms and development sequences, which usually govern the composition of the resulting ecosystem. Both of these scheme types involve some characterisation of the peat deposits as a necessary consequence of describing the current ecosystem and the development sequence that can be inferred from it.

Ecological schemes vary but usually depend on the availability of certain nutrients, a measure of the acidity or the Carbon/Nitrogen ratio:

Table 2: Measures of mire nutrient status synthesized from Koster & Favier (2005, 169)

Measure	Oligotrophic	Mesotrophic	Eutrophic
Total water nitrogen content	0.01- 0.25 mg/l	0.25- 0.6 mg/l	0.6- 1 mg/l
C/N Ratio	>33/1	33/1 – 20/1	< 20/1
pH	Fens- 4/5 Bogs- 3/4	4.8- 6	Fens- 6-7.5

They might take one of these measures, or a number of them in combination.

Other, more specific schemes take just one type of environment, and then deal with classifying the mesotopes and macrotopes that exist within it, usually based on landforms and plant species. For example Lindsay (1995) is concerned only with ombrotrophic mires in the UK, and classifies these largely upland raised bogs first in terms of the gross morphology of the peat dome, using the pattern of pools and ridges that have developed, and then classifies the mesotopes using a combination of morphological characteristics and hydrogeomorphic categories, before classifying the microenvironments by their relative position in the pools and ridges, and the plant communities. He also makes an interesting and perhaps useful distinction between primary bog, and secondary growth on a bog that has been cut or fire damaged. Obviously, in the latter case the peat sequence will be truncated; being able to recognise this is important to palaeoclimatologists and archaeologists alike.

There are also closely linked schemes for classifying peatland environments that in some way reflect the origin of the peat formation.

Geogenetic classification uses the landform the mire developed on as the basis for the classification. There are four main types; ombrogenous mires, which grow over surface depressions fed by rainwater; topogenous mires that form in topographic depressions fed by groundwater; liminogenous mires form that along lakes and slow flowing streams; and soligenous mires that form on slopes and depend on moisture seeping through the soil layers on the slope. Upland raised bogs are usually ombrogenous mires, and blanket bogs are soligenous and ombrogenous.

The hydrogenetic classification scheme has been developed to classify the mires in Germany and central Europe. It is based on the position in the landscape and the water

inputs, and contains eight main types; former lake mires; swamp mires; floodplain mires; percolation mires; spring mires; slope mires; kettle hole mires; and rain fed mires (upland and lowland). Slope mires correspond to blanket bogs, and rain fed mires to raised bogs, in the UK terminology.

The hydrogeomorphic classification scheme is very extensive, and is perhaps more descriptive than categorical as a result. It uses both the form and topography of the mire to make distinctions. A variety of hydrogeomorphic classification is used by Lindsay in the example above, to classify the mires at macrotope and mesotope level.

5.2.2 Classifying peat

Classifications of peat itself are more concerned with the physical and chemical properties of it, rather than specifically with the plant and animal communities that it sustains and is sustained by. Thus they potentially have more relevance to archaeologists as we are more interested in the peat and what it buries. These types of classification tend to be used in commercial evaluations of peat, and in the investigation of its physical and chemical properties from a soil science or engineering point of view. There are very many attributes that can be considered, but the primary divisions are based on botanical composition and state of decomposition, as many of the further characteristics relate directly to these. Obviously, the botanical composition and the decay state will be dependant on the mire type as a whole, so these classifications do relate, in complex ways, to the mire type.

Peat environments inhibit decay to the extent that often, the predominant vegetation type can be discerned in the field by eye or with a hand lens. It should be relatively easy, in unhumified peat, to distinguish between moss peat, herbaceous peat and wood peat. Where possible, these plant macro remains are identified more closely to allow an assessment of the type of bog in which they were laid down and possible nutrient/ carbon contents for economical assessments.

Some peats show a higher level of humification due to different conditions allowing more or less decomposition of the preserved organic materials. This is usually a subjective estimation based on an assessment of the colour, structure and fibre content of the peat in the field. It is important to examine colour immediately on exposure as oxidation occurs rapidly and peat is often uniformly black within minutes of exposure.

Humification is related to bulk density and the fibre and carbon content of the peat and so is important in both economic and engineering assessments (Clymo 1983, 162). The Von-Post 'H' scale is commonly used to asses this in the field (Clymo 1983, 162; Hobbs 1986, 78), and the Soil Survey of England and Wales use an adapted version (Burton & Hodgson 1987).

The relationships between the specific types of peat a given system will produce, and the origins, water supply and ecology of that system are complicated and interrelated. An archaeologist working in these environments needs to understand the links as the formation conditions of a bog will influence the type of archaeology likely to be present, its likely state of preservation and the implications the site's development, hydrology, and physico-chemical properties might have for geophysical anomaly detection.

5.2.3 Archaeological classification schemes

Archaeology-specific schemes in the UK are very simple. They are based on those used by the soil survey, which are a mixture of the geogenetic and ecological schemes. The MAREW project simply split the types between upland and lowland, based on a soils classification cut off at 200m OD (Van de Noort *et al.* 2002a, 5). This resulted in a triple distinction for wetland environments; upland peat, lowland peat, and lowland alluviated wetland which is pervasive throughout the archaeological literature and strategy documents (Howard-Davis *et al.* 1998; Olivier & Van de Noort 2002; Hodgson *et al.* 2005; English Heritage 2008).

5.2.4 Resulting scheme for this project

Taking into account all of these schemes, classifications of peat environments are pragmatic, and driven by the needs of the researcher, rather than being universal. The upland (i.e. ombrogenous upland blanket mire, perhaps covered by raised bog)/lowland (i.e. topogenous mires, perhaps covered with raised bogs) classification is used in this research, as the ombrogenous/topogenous distinction it implies is the most important determinant in the type of mire that forms, and its vegetation and chemistry. It also indicates differing formation processes and periods, which will influence the types of archaeology likely to be present (Van de Noort *et al.* 2002a, 9). This categorisation has been used for simplicities' sake in the selection of case-studies.

The more complex characterisations used in ecology and pedology are important, and all case-study sites will need to be understood at this greater depth because an understanding of the formation processes of mires is vital to understand the geophysical responses to them.

Table 3: Peatland Classification Scheme for the project

Environment type	Description	Issues for survey
Type 1: Lowland peat with intra peat archaeology	This site type includes river valley peats, such as those developed around lakes and streams, and perhaps wetland areas subject to coastal inundation. These would include valley mires, basin mires, open water transition mires and flood plain mires. It has the potential to include intertidal zones and salt marshes in coastal zones.	The main challenges here are locating material within thick (usually waterlogged) sediments with potentially little differentiation in the physical and chemical properties of the target from the surrounds. The best-known examples of these kinds of sites involve the preservation of prehistoric wood, usually in the form of trackways or platforms in an extant marsh (or lake) which have been overtaken and buried by the further growth of the mire. Classic examples would be Flag Fen, the Sweet Track and the trackways of the Federsee in Northern Germany.
Type 2: Lowland peat with sub-peat archaeology	This combination of site - depth and environment is more common in coastal wetlands and in river valleys. As estuaries are deposited or as alluvial plains build up, previously dry sites are buried or even inundated and thus preserved.	The archaeology is buried under very deep deposits, which may have their own complex stratigraphy and masking signatures. The archaeology may well be poorly differentiated from the overlying peat and alluvium in terms of its physical and chemical properties, especially if still waterlogged. It is also possible in coastal zones that this material will be brackish causing problems for GPR. We therefore have a slightly different set of challenges to overcome than when dealing with Type 1 sites.
Type 3: Upland peat with intra peat archaeology	This combination of archaeology and environment is highly unlikely due to the climate history of the UK, settlement patterns and the causes of upland peat formation.	The issues in this type of environment would be much the same as Type 4 environments, with the added complication of trying to sense small finds and objects within a thin layer above a strong geological parent. On Dartmoor there are thick peat deposits with the potential for intra-peat sites and finds. The challenges would be much the same as Type 1 and Type 4 environments with the added complication of an igneous parent and difficult access and weather conditions.
Type 4: Upland peat with sub peat archaeology	The blanket bogs and raised mires that occur in upland areas of poorly drained cleared land, that overlie archaeological deposits laid down on a previous land surface- though the archaeology might protrude up through the peat. The shallow soils cause additional complexity- in time-terms the archaeology is sub-peat, but also intra and supra for detection.	The challenges in these environments are much reduced compared to lowland wetlands and peatlands. The deposits are relatively thin when compared to valley peats, and there is often a continuation of archaeology from above surface to areas under peat, thus there is often a 'known' to work from. The proximity of the parent and the fact that much of the archaeology will be upstanding from that (stone field boundaries, hut circles, stone monuments) is likely to cause issues. Where the peat is only a thin layer, it might actually be quite hard to detect upstanding rock as distinct from the strata it rests on. The geological parents that allow these raised bogs to develop are normally igneous and these parents can pose difficulties for magnetometry surveys.
Type 5: Peat with supra peat archaeology	Given the environmental and settlement pattern conditions of the UK, we are unlikely to ever (within the British Isles) to have prehistoric archaeology that lies on top of or cut into peat deposits.	This removes the problem of depth, and exposes features to potentially being visible to surface inspection (field walking or remote sensing). Most geophysical techniques employed in archaeology 'discount' the first 30 cm or so readings as noise, or are processed in ways that assume this. Surface level anomalies could prove quite hard to detect in geophysical data.
Type 6: Other 'wet' environments	Included as complex relationships exist between this environment and the lowland peats.	These environments pose problems largely similar to waterlogged lowland peats, but they have the potential to be brackish, or contain a high clay content, which causes problems for GPR as it results in the attenuation of the signal.

5.3 The selected sites and rationales

After a careful research process into potentially suitable areas and specific sites, and following discussions with National Park Archaeologists and local HER officers about suitable sites in identified landscapes, four case study areas were selected according to the following criteria:

- Must reflect at least one environment type
- Must have previously known archaeology and be well documented enough for assessment of techniques
- Desirable to have real research questions that geophysical survey can meaningfully contribute to
- Desirable to have ground-truthing opportunities
- Be safely accessible for survey

Further details of the site histories and aims and objectives specific to each are discussed in the case- study chapters (8-12) and so will not be repeated here.

Table 4: Case study areas and sites

Case-study Area	Environments represented	Reasons for selection
Area 1: Carn Meini *Sub-sites:* *Llach-y-Flaiddast* *(passage grave)* *Croesmihangel* *(barrow)*	Type 4	Different parent geology from site 4, allowing comparison of response. Part of SPACES project so ground-truthing work likely as part of wider ongoing research. From a less intensively studied part of the UK, so opening new avenues of research.
Area 2: The Sweet Track *Sub-sites:* *Canada Farm* *(active bog)* *Shapwick Burtle* *(landfall of trackway)*	Type 2	The archaeology is very well understood. It is a small target which will be a real challenge for the techniques. The depth of burial is less than 1m, in contrast to site 3. GPR has previously had success on the site.
Area 3: Flag Fen *Sub-sites:* *2 areas within the site, one over the platform and one over the post alignment*	Types 1, 2 and 5 (5 not prehistoric)	High potential for ground-truthing work to be permitted. Several well understood large features to target. Waterlogged wood forms a large part of the archaeology but bronze finds are also known. Multiple periods and uses of the landscape are present in a (relatively) small area. There is a long history of excavation and research on site, including geophysical survey. Complex interleaved peat and alluvial deposits provide a challenge for the techniques.
Area 4: Southwest Dartmoor *Sub-sites:* *Yellowmead Down* *(Stone circle and cairn)* *Drizzlecombe* *(Stone rows and cairns)*	Types 4 and 5 (5 not prehistoric)	Contrasting parent geology to Area 1, allowing for comparison. Selected sites have useful and specific archaeological questions to be answered. There is some medieval supra-peat archaeology and this allows the impact of later activity on the responses to be assessed. DNPA are enthusiastic about ground-truthing work.

Chapter 6: General geophysical methodologies

6.1 Introduction

This Chapter is an overview of the various geophysical techniques employed in the field for this research. It summarises the physical principles involved in each geophysical technique, the detection capabilities and limits, any known issues or conflicts and a full technical description of the instrumentation employed for each during the course of this research. The precise field methods and instrument settings were tailored to each case study site, as were instrument selections and these details are discussed in the relevant case study Chapter (Section 4, chapters 9 – 12). Information in this chapter is synthesised from a number of key texts (Scollar *et al.* 1990; Gaffney & Gater 1993; Clark 1996; Kearey *et al.* 2002; Gaffney & Gater 2003; Conyers 2004; Johnson 2006b; English Heritage 2008), and other sources where specifically cited.

6.2 Resistivity

6.2.1 Physical principles

This technique relies on a very basic physical principle; soil with more moisture in it will be less resistive to an electrical current. The fills of pits and ditches and other features will have more pore spaces and trap more moisture, and buried walls, floors and other surfaces will be more compact and will thus have less moisture. By injecting a known current into the earth and measuring what is transmitted over a known distance, the resistivity of the earth can be determined using Ohm's law:

$$I = \frac{V}{R}$$

Where

      V is the potential difference between the injection points, measured in Volts: *V*
      R is the resistance of the earth, measured in Ohms: Ω
      I is the current through the earth, measured in Amperes: *A*

Once the array dimensions used to inject and measure the resistance are understood, a conversion can be made to electrical resistivity; a measurement specific to the volume

of the material being measured and expressed in Ohm meters (Ωm). This conversion is not always necessary if only one array type or size has been used for the survey as the pattern of observed resistances is used as a single dataset and comparisons are relative within it. If however, different array configurations or sizes are to be compared, the measured resistances must be converted into resistivity. It is common to refer to both types of survey as 'resistivity survey' in archaeological parlance; in this document if conversions to resistance have been made, this will be clear and data plots will reflect the difference in units (Ω vs. Ωm).

As archaeologists began to realise the potential of electrical resistance surveys after WWII, a number of array types used in geology were experimented with, including very early surveys by Atkinson (1946). Perhaps the most commonly used was the Wenner array (see Figure 6.1), but it was time consuming and cumbersome to work with at the 1m intervals needed for archaeological prospection. In the 1960's and 70's a concerted research effort went into developing an alternative that worked for archaeological survey. Much of the important work on the now near-ubiquitous twin probe array was carried out at Bradford University by Aspinall (Gaffney & Gater 2003, 30-32.). Though it is markedly less sensitive (producing around a 15% change over a given anomaly, rather than up to 50% with a Wenner array), it was adopted by archaeologists. The separation of the two dipoles has two advantages. Firstly, the fixed location of the remote probes (so long as it iss at sufficient distance- about 30 times the mobile probe separation), means that the variation in the background drops to about 3%, which is less than most archaeological anomalies, allowing them to stand out more. Secondly, the orientation of the two probes relative to each other, in theory, does not matter, allowing the mobile array to survey in zig-zags, and the orientation be changed to negotiate obstacles. At a 0.5m separation at the mobile probes, the array is sensitive to about 0.75m into the ground; this encompasses the depth of most archaeological deposits on conventional sites. It also produces a single peak over an anomaly, unlike the much more complicated responses of the other arrays, greatly simplifying interpretations. For these reasons, the 0.5m twin probe array has become the resistivity survey method of choice, at least in the UK. This is perhaps a shame, as some researchers are now realising, as advances in processing power and sensors mean that other arrays might be worth reconsidering, and our

understanding of them now needs to be brought up to speed (Bevan 2000b; Cheetham 2001).

Resistivity survey can also be used to take transects of readings, rather than area surveys, or a series of readings in one place with widening array dimensions to build up a picture of the change in resistance with depth. These two methods can be combined, either manually or with computer controlled selection of electrodes through a large array. This is know variously as Electrical Imaging, or Electrical Resistance Tomography, or Electrical Resistance Profiling, and is discussed in detail in Chapter 7, as it is largely a data manipulation process, based on the physical principles discussed above. In this thesis, the acronym ERT is used.

6.2.2 Detection capabilities and limits

Resistivity survey is largely a measurement of relative levels of moisture retained in the soil, which in turn is a reflection of the porosity of the soil. It relies on these variations being great enough to be measured by current equipment, and on them occurring over a large enough area of the ground as to be measured. The depth and resolution limits of the array are largely determined by both the array type and the separation of the measuring probes.

It is also an active system, in that it relies on being able to inject the current into the substrate. This can involve overcoming significant contact resistance at the probes: at times, they might need watering, for example, or they might not be able to get through an interfering surface layer, like a very well trodden path, or asphalt. Resistivity surveys are not, as a rule, possible over man made surfaces. Standing water on a site can be a problem as well, potentially just conducting the current between the probes, if the water is at all brackish, as it acts as an electrolyte.

Generally speaking, this technique is good for locating buried walls, foundations and other stones structures, and locating ditches and larger pits.

6.2.3 Known conflicts and issues

Given their normal moisture properties, some features (pits, ditches) might be expected to always show as low resistance features, due to their greater porosity and organic content, leading to more retained moisture, but Clark (1996, 48-56) shows us the situation is more complex that that with some features showing as high resistance

unexpectedly. These changes were due to precipitation changes throughout the year, so the archaeologist must be aware of the weather during and before the surveys, and think carefully about what might be giving rise to any anomalies.

6.2.4 Instrumentation employed

The surveys used an RM15 A, with both a twin probe 0.5 m frame and probes, or with the PA20 1.5m frame and 6 probes at separations of 0.25, 0.5, 0.75, 1, 1.25 and 1.5m, using the MPX15 attachment to control the reading sequence appropriately.

6.3 Magnetometry

6.3.1 Physical principles

Magnetic survey exploits the natural magnetic field of the earth, more specifically the slight, local perturbations caused in this by magnetised objects. Objects or substances only need to be very weakly magnetised to have a tiny but measurable effect (in nanoTesla: nT) on the overall field of the earth generated by the circulation of molten iron at the centre of the planet. In archaeological contexts this means that some metals, some stone and ceramics can be detected, if present in enough quantity (depending on the local conditions and the sensitivity of the equipment), as they are either inherently magnetic or they have been heated past their Curie point and when cooled, their electrons have re-aligned in the direction of the Earths magnetic field at that time. This is known as thermoremnant magnetism. The field changes over time, so, by the time the object is surveyed, it is out of line with the earth's field, and thus disturbs it. Other properties of deposits can become magnetically enhanced enough to have a detectable affect by other means.

Soils and other deposits on sites occupied by humans can become magnetically enhanced by three processes. Firstly, topsoil generally has a higher magnetic susceptibility than the substrate, and when excavated features are filled with topsoil they produce a positive response. The addition of fragments of thermoremnantly magnetic material from hearths and fires over time increases the effect. The actions of magnetobacteria as they exploit minerals in these deposits further enhance their magnetism. In some cases, the chemical and physical effects of human occupation on the soil increase its magnetic susceptibility; so much so that enhanced MS in soils is often taken as an indicator of human influence on the soil profile (Clark 1996, 66). As this material is permanently within a weak magnetic field (the Earths), it is

magnetised and so forms (usually) positive anomalies. In some cases however, archaeological features such as pits and ditches show as a negative; this is when the soil or surrounding matrix is highly magnetised, and pits and ditches represent a break and disturbance in that, which returns a weaker signal.

Strongly magnetic anomalies show as dipoles, with a negative dip to the south and a strong positive to the north (at the latitude of the UK); precisely locating the feature that cause the anomaly is rarely an issue as they tend to be quite large if presenting this sort of signal.

6.3.2 Detection capabilities and limits

From the outset of this type of survey (WWII military applications) the technology involved has been developing towards both greater speed and ease of survey and ever increasing sensitivity.

There are generally two configurations of magnetometer (though there are several types of magnetometer); either a total field measurement or some sort of dual configuration (either using a base station, or more commonly two sensors on a vertical mounting used as a gradiometer). The advantage of using two measurements, rather than a single total field device is that one is used (the base station or top sensor in a gradiometer) to measure the general changes in the field; diurnal drift, changes from telluric currents etc and subtracts that measurement from the second sensor, which then (in theory) just gives a measurement of the variation in its immediate vicinity.

As a result of the compromise between sensitivity and the time needed to take each reading, and its relative ease of operation, the fluxgate gradiometer has been most widely adopted for archaeological geophysical surveys. In fact, such is its ubiquity in the British discipline; it has been aptly nicknamed the 'workhorse' of British geophysics by Clark. Since he was writing, improvements in the technology and computer signal processing mean that there is now a dual 1m gradiometer configuration, the Bartington Grad601. This is used for very rapid area surveying with improved depth sensitivity over the 0.5m configurations such as the Geoscan Research FM36 and FM256. There have also been improvements to the more sensitive caesium devices in terms of the time it takes to make each reading. These developments have been based in Europe and are, in part, a response to the different

soils, geology and agricultural regimes on the continent. In practice, much of the surveying done in the UK is still carried out with fluxgate gradiometers, be they the Geoscan model or the Bartington. This research used both instruments, depending on local conditions such as vegetation cover and the depth of the expected archaeology. At Flag Fen, the archaeology was expected to be buried more deeply, and there was less standing vegetation to knock the larger Bartington instrument. All of the other sites made used of the Geoscan instrument because of the suspected depths of buried and the manoeuvrability of the instrument.

In practice, the 0.1nT resolution of these instruments has proved adequate for detection of archaeological sites in the UK, and the finer detail that is missed is compensated for by the ease of operation and the speed of measurements.

6.3.3 Known conflicts and issues

Areas with a lot of magnetic noise; either from modern ferrous material or electrical currents such as overhead power lines, or from thermoremnantly magnetic rock such as basalt can be problematic to survey. The archaeological anomalies are of a smaller magnitude than the interference or geological changes, and so do not show up without careful processing, or are simply swamped.

Overburden is also an issue; typically these instruments are only sensitive to archaeological anomalies up to about 1m deep in the soil, depending on the strength of the feature and local soil conditions. This is aptly demonstrated by the surveys in the vale of Pickering where field systems can be seen fading out of visibility as the depth aeolian sand deposits increases over them (Weston 2001).

6.3.4 Instrumentation employed

For this research, Geoscan fluxgate gradiometers (an FM36 and an FM256) and a Bartington DualGrad 601 were employed, depending on the individual site conditions and the expected depth of burial of the archaeology. The emphasis of this research has been on utilising commonly employed prospection techniques. Fluxgate gradiometers of the models used here are by far the most commonly used geophysical tools on archaeological sites in the UK. Though we expected any anomalies to be of fairly small intensity, we also expected the background to be fairly quiet as the case study sites are generally remote and not subject to modern ferrous rubbish or other environmental noise, such as busy roads.

6.4 Frequency domain electromagnetic

Technically, five different types of geophysical survey use Electromagnetic means to measure properties of the ground. These are Frequency Domain Electromagnetic surveys, time domain electromagnetic surveys (pulse induction metres), GPR, metal detecting and Magnetic Susceptibility (MS) surveys using field induction. This section deals with Frequency Domain EM survey, and where 'EM' or Electromagnetic survey is referred to in the text, it is this type of survey that is being referred to. However, all types of electromagnetic survey rely on the way the ground responds to the propagation of EM waves. The exact properties of the soil being measured depends on the frequency of the EM waves induced (Gaffney & Gater 2003, 43- 44).

6.4.1 Physical principles

A solenoid (coil of wire around a magnetically susceptible core) either generates an alternating current in the presence of a time varying magnetic field, or creates a time varying magnetic field when an alternating current is passed through the coil.

Frequency Domain EM survey exploits this physical principle by using two such coils. One creates an EM field, which in turn excites the miniature magnets/ coils in the ground, and creates both eddy currents and excites magnetic susceptibility (see Figure 6.2). These create their own small electrical and magnetic fields which in turn affect an EM field being generated by a second, receiving coil; these mild perturbations are measured in different parts of the signature; the quadrature and inphase components (Clark 1996, 36). The alternating current produced by the transmitting coil produces a response in the ground that is detected by the receiving coil that is proportional to the conductivity of the ground. The magnetic susceptibility (MS) can also be measured because '*while the rate of change of the magnetic field measured in the receiver is proportional to the conductivity, the magnetic signal is related to the strength of the magnetic properties of the soil*' (Gaffney & Gater 2003, 43).

There are numerous potential coil combinations, with very complex field geometry. In some EM instruments, the coils are perpendicular but oriented 55 degrees from horizontal, which means the transmitting and receiving field cancel each other out, leaving just the perturbations in the latter, which are output to a logging device. Arrangements also exist with one coil horizontal and one vertical.

In other instruments, the coils are coplanar but used either vertically or horizontally oriented with respect to the plane being surveyed. In these instruments, additional electronics is needed to 'cancel' the induction signal from the recorded response.

Changes in the quadrature component of the signal relate directly to the conductivity of the ground; and given that the instrument operates over a known volume of soil, this can be directly expressed in mS/m. The inphase responds to the magnetic susceptibility of the material surveyed and is expressed as that response in ppt of the primary magnetic field. It is not an absolute measurement, so caution needs to be taken when comparing measurements between different surveys. It is also not directly comparable with laboratory measurements made using the Bartington MS2B, which produces results in SI units (Dearing 1999), as an expression of the volume specific magnetic susceptibility.

Uptake of this type of survey has not been as great as Clark tentatively predicted (1996, 34), perhaps due to the complexities of the physics involved and the problems of interpretation associated with the complicated relationship between the two measurements, and changes in the instruments sensitivity over depth that make interpretation challenging (see Figure 6.3).

The technique has had a lot of attention in continental Europe, particularly France, with a very great deal of work done on EM survey for archaeology by Professor Tabbagh (1986), notably where an EM survey over a peat environment allowed the detection of a Bronze Age trackway indirectly, by locating the hoards that had been placed along its length. Increasingly common is the use of larger scale surveys with levels of resolution too low for archaeological features to be detected, but greater depth penetration to characterise landscapes as part of culture resource management (CRM) investigations (Carey *et al.* 2006; Bates *et al.* 2007; Conyers *et al.* 2008).

6.4.2 Detection capabilities and limits

The detection capabilities of these systems vary a great deal and are largely a function of the array size, and the frequency of the EM signal the coils are producing. This means they can be employed (as discussed above) to measure changes on geological

scales, right down to archaeological ones, and laboratory measurements of even smaller changes.

In practice, the most commonly employed instrument for archaeological purposes is the Geonics EM38 (in various permutations). It has a coil separation of 1m, with coplanar coils that can measure both the quadrature and inphase components of the response that give the conductivity and magnetic susceptibility. Generally speaking with the coils held vertical to the ground surface the EM38 is most sensitive at about 0.3 to 0.5m deep, and less sensitive to surface changes, which can be advantageous where there is a disturbed ploughzone adding noise to conventional surveys. With the coils horizontal to the ground, the instrument is most sensitive at the surface. This is the case for both the quadrature and inphase response, but the inphase response is complicated; the sensitivity curve goes negative at about 0.5m deep for a time; this means a positive anomaly at that depth might produce a negative response, or just be cancelled out by this effect. Understanding this complex response is key to making good use of this instrument, and this has been a barrier to the wider uptake of the technique (see Figure 6.3).

The Geonics EM31 is a 4m array that has been successfully employed in geoarchaeological studies and locating larger structures, but generally has poor resolution (greater than 1m), of little use to accurately image archaeological scale anomalies.

One major advantage of EM survey is that, unlike resistivity survey, it does not rely on being able to overcome a contact resistance to inject electrical current into the ground, so it can be used in very dry environments, situations with standing water, and where there are other problems with the surface conditions for resistivity survey. The instruments are usually self contained; the EM38 can be handled by one person very effectively, as can the EM31. Larger systems may require a towing vehicle or other arrangements, but for instruments commonly used on archaeological surveys, one person is sufficient to operate the system, and there are no trailing wires, as there is with resistivity survey.

Another advantage, when the equipment is built to do so, is that both conductivity and MS can be measured in one survey, rather than two, saving on operator time and fatigue.

These systems should, in theory at least, be better at detecting lenses of MS enhancement and thin layers of material than a gradiometer, which would only see the edges of such a layer and not the spread of it, as it measures rates of change rather than the total field effects (Gaffney & Gater 2003, 44).

6.4.3 Known conflicts and issues
As the technique relies on EM induction, it can suffer in highly conductive environments or where there is a lot of saline water present as the EM energy is conducted away rather than setting up reciprocal fields and eddy currents.

There can also be problems when the survey includes objects or deposits that are very conductive or very magnetic; the effect on the induced fields can be so great that a response appears in the other part of the signal; i.e. highly conductive objects show up as MS anomalies and vice versa. This further complicates the response of the instrument.

Modern conductive rubbish in the topsoil can cause problems with spiking and signal-leak.

6.4.4 Instrumentation employed
This research used a Geonics EM38B; a 1m coplanar coil instrument that allows both the quadrature and inphase to be measured at the same time. The instrument was used with a Polycorder data logger, and on some of the sites a modified snowboard was used as a sled to survey with the instruments' coils in the horizontal orientation without damaging or triggering the adjustment dials and reading trigger button.

6.5 Ground penetrating radar

6.5.1 Physical principles

Ground penetrating radar (GPR) is based on similar principles to those used in aviation radar (**RA**dio **D**etection **A**nd **R**anging). Rather than propagating an electromagnetic waveform into the air and bouncing it off objects to detect them, it propagates a waveform into the ground and measures (usually) the two-way travel time of pulses of the signal as they are returned from buried objects and interfaces.

An antenna is used, usually with a central frequency somewhere between 100MHz and 1.5GHz, to send very rapid pulses of electromagnetic energy, which are transmitted as waves into the ground. These are reflected back to a receiving antenna at the surface when there are significant changes in the relative dielectric permittivity (RDP) or magnetic permittivity of the subsurface, often as positive and negative amplitude wavelets. The time each pulse takes to be reflected back is used to make assumptions about the depth of the reflecting material. A composite is generated from all the wavelets created over the many changes in the soil over depth at a given location is called a reflection profile.

In practice, the pulses of the antenna happen too fast to be digitally recorded, so a series of samples is used to build up a reflection profile (usually 512 or more). To collect surveys, a transmitting antenna is dragged along a transect, followed at a fixed distance (usually) by a receiving antenna that measures the returned wavelets and the two-way travel time, building up stacks of thousands of reflection profiles along a traverse. When digitally recorded and recombined, these can be imaged as a radar profile; a two dimensional slice through the ground along the survey transect, showing the reflecting layers and objects. Reflections are not straight forward to interpret because the energy leaves the antenna in a cone, so anomalies ahead of the antenna will produce a response before the antenna is directly over them, and vice versa. Over strongly reflecting targets, this produces parabola and the shape of the parabolas in a survey can be used to estimate the radar velocity in the sediments.

These 2-dimensional radargrams can be further combined (if properly georeferenced) into a three dimensional data set to produce plan view images of anomalies and

changes in the amplitudes of the response- an indicator in the 'strength' of the reflecting anomaly (Clark 1996, 118-9; Gaffney & Gater 2003, 74-6; Conyers 2004, 23-6).

There are a lot of factors that influence the choice of antenna and acquisition parameters, such as the expected spatial extent of the anomalies (in three dimensions) vs. the transect spacing and wavelength (which has a complex relationship with the antenna frequency and the RDP of the material), the known or suspected soil/sediment properties, and the depth of burial of the targets. In practice, this means GPR is often perceived as a technique that requires a lot of experience or technical knowledge to properly employ. This, combined with perceived 'underperformance' given the complex factors affecting how the radar signal will behave in the ground, have meant the technique is less often employed in archaeology, but the situation seems to gradually be changing. In the 1990s Clark (1996, 118) stated that because of problems caused by the wetness of soils, GPR had yet to see many applications in British archaeology. In 2003 Gaffney & Gater (48) stated that it was increasingly used on urban sites in the UK, not because it worked especially well, but because it worked better than the alternatives. They also noted that it was increasingly being used on greenfield sites, but the soil composition on UK sites in general remained a problem. By 2008 GPR was considered one of the more 'routine' techniques employed here (English Heritage 2008); perceptions of the limits on operating environments for this technique have changed as the complexities of RDP vs. radar velocity and attenuation have been worked out.

As discussed above, GPR has a relatively long history of use in peatland environments outside archaeology, mainly to map and quantify peat deposits and for engineering assessments. It has also had some limited successes in locating archaeological remains in lowland peat.

6.5.2 Detection capabilities and limits
Despite having a much wider range of applicable environments than was the perception when Clark was writing there are still limitations to what can be detected with GPR.

Firstly, the target must have sufficiently contrasting RDP and a sharp enough interface to be detected: gradual changes in RDP or sudden but slight changes will not be detected. RDP is defined as 'the ability of a substance to store and allow the passage of electromagnetic energy when a field is applied' (Gaffney & Gater 2003, 50).

Secondly, the signal must be able to propagate to and return from the depth of the target; in an environment where the signal rapidly attenuates it may not be possible to get a return from the required depth, despite using a low frequency antenna.

Linked to this problem is that of the size of the radar footprint; a complex interaction between the antenna frequency, the depth of the target and the RDP of the matrix change the size of the 'footprint' of the EM pulse; the area it is actively looking at in the ground. Any anomalous material needs to make up a significant percentage of this footprint to be detected, so the minimum size of object that can be detected and the optimum transect spacing are dependant not only on the antenna, but also on the RDP of the soils/sediments and the depth of burial. The RDP of the sediments and the depth of burial can sometimes be known or estimated before the survey, but often cannot, meaning some trial-and-error is necessary to determine optimal survey strategies.

In practice, this means that, generally speaking, with 250-500MHz antennae, archaeological anomalies 0.5m across are about the smallest that can be detected in routine survey, unless they provide a very strong contrast with the surrounding matrix. It also means that in area surveys, the maximum transect spacing ought to be 0.5m, to ensure no anomalies of this size are missed between transects. It also means that even with lower frequency antennae, the maximum depth of meaningful archaeological investigation is about 4m. Much greater depths (in the order of several km) have been achieved through ice, but this was to map landforms, not archaeological-scale anomalies.

6.5.3 Known conflicts and issues

There are some known issues with radar survey, and some common misconceptions. Firstly, wet environments are not necessarily an obstacle to survey, and neither are

clay soils; it just depends on the physical and chemical properties of the water and or clay.

Water itself is a good propagator of the EM wave and surveys of lakes through the bottom of a boat and using the water column to conduct the signal to the sediments at the base have been very successful. There have also been successful surveys waterlogged sediments (Clarke *et al.* 1999a; Utsi 2004). The problem comes when there is any salt present in the water, as saline water is a very effective conductor which rapidly attenuates the electrical component of the signal, causing the wave propagation to fail and the signal to be lost. This can happen with saline intrusions in waterlogged sediments, but it can also be a problem in seemingly dry (and held to be 'ideal') conditions over sandy soils if there are salts present in the interstitial water. Other minerals can cause similar problems; if a material is a relatively good conductor, or has become so due to the chemical makeup of the pore water (for example, in reducing conditions, which tend to be acid), then attenuation is more likely to be a problem. The same thing can happen with the magnetic component of the waveform; highly magnetically permeable soils (e.g. those with high magnetite content) can also be high attenuation environments (Conyers 2004).

Clays present a problem if the clay is a swelling clay, which can hold water in its matrix, making it a conductor, and this likely to attenuate the signal. Some two-layered clays do not have this property, but making adequate distinctions between the two types in the field is not practicable.

As can be seen, sometimes it is not possible to know in advance if GPR will 'work' on a site without advanced knowledge about the geology and expected archaeology. Even with such foreknowledge, it can take time and trial and error to get the right antenna, travel time window, and estimated velocity to produce a good survey.

GPR also operates over a much used part of the EM spectrum, for radio, television and communications transmissions. As such interference can be a problem, particularly in environments where there are a lot of radio transmissions in the frequency band being used for survey (as has been the author's experience surveying with 500MHz and 800 MHz antennae on Salisbury Plain, a military training area).

It is essential to maintain good ground coupling (keeping the antenna in constant contact with the ground or at a constant offset) which can be a significant problem over rough terrain or in areas with rapid changes in vegetation cover.

6.5.4 Instrumentation employed

This project employed a MALA Geosciences RAMAC X3M system, utilising Mala shielded 250 and 500 MHz antennae. These antennae are fixed position so cannot be used for the wide angle ranging and reflecting (WARR) or common mid-point (CMP) methods of radar velocity estimation. A survey wheel was used for continuous distance measurement during survey, rather than the stepped or fiducal markers method. The exact settings, survey strategy and acquisition parameters were adjusted to suit each individual case study site, and are detailed in each Chapter reporting on them.

Section Three: Data processing and ground-truthing methodologies

This section contains two chapters that deal with the post-field handling of the geophysical data, and the principles that guided the ground-truthing work done on some of the sites. Chapter 7 deals with the computerised data processing and looks at the two dimensional surveys, which were processed in GEOPLOT3 (Geoscan Research 2006) and then the pseudo-three dimensional data, the GPR surveys and the multiplexed resistivity work, which were dealt with in specialist programmes, GPR-SLICE (Goodman 2008) and Res2DInv (Loke 2005) respectively.

Chapter 8 is an overview of the principles and strategy behind the ground-truthing investigations; the specific aims and approaches on each site are discussed in the relevant chapters in Section 4.

Chapter 7: Data processing principles

This Chapter deals with the theory and principles of geophysical data processing. Proprietary software has been used in the piece of research, and alternatives exist so this Chapter will not deal with the specifics of which tools and settings were employed (though these are included Appendix A, associated with each case study site), but rather with the broader principles and implications of these processes on the resulting data plots.

7.1 Introduction

The processing of geophysical data can be a contentious issue. The 'raw' data gathered in the field is already an abstraction from the 'real' characteristics of the sediments. Any further manipulation of the data takes the geophysicist further away from the absolute measurement of the physical properties of the ground. On the other hand, processing techniques can significantly enhance the interpretability of geophysical data sets, correcting for operator error or unavoidable alterations to the data caused by the fieldwork conditions or environments. They can also be used to enhance, not just correct, the collected data, allowing the archaeologist to emphasise certain parts of the image and present the data in innovative ways that allow better insights into the characteristics of the buried features.

Any manipulation of the data can, however, result in the distortion, loss or introduction of anomalies and patterns in the resulting images. It is therefore vital that these operations are carried out with an understanding of exactly how the data are being changed by the selected process, rather than being operated as a list of 'standard processing steps' with little adjustment for the peculiarities of the individual site and survey being taken into account. With geophysical data acquisition and processing becoming a routine part of commercial archaeology in the UK there is a real danger of such a 'black box' approach being adopted by less experienced surveyors, with a resulting problem in the quality of the interpretation and usefulness of the surveys. The information in this Chapter is synthesised from a number of sources (Scollar *et al.* 1990; Clark 1996; Loke 2000; Wheatley & Gillings 2002; Gaffney & Gater 2003; Lock 2003; Conyers 2004; 2006a; Geoscan Research 2006; Goodman 2008).

7.2 Two-dimensional surveys

7.2.1 Introduction

In the main, in conventional geophysical survey over a defined area, the data will usually be handled and presented as a raster. A raster is an image made of cells, where the display properties of the cell are related to the value of the cell. By this means, it is possible to display the 400 readings taken in a 1 x 1 metre survey over a 20m Grid as a greyscale image where the darkness/lightness of each 'cell' in the image is governed by the reading that corresponds to that location in the survey Grid. Almost all digital images (including photographs) are rasters; they just vary in complexity, both in terms of the numbers of cells in the raster (commonly called pixels in digital photography) and in terms of the palette of colours used to display them. Figure 7.1 is an example of a simple binary raster, displayed next to a 20 x 20 raster of resistivity survey data.

In this research, the techniques that have been processed using this basis are the gradiometry, the area resistivity surveys, and the EM surveys. This is because all of these techniques, regardless of the actual depth they are sensitive to, or the depth information that can be inferred from them, essentially deal in two-dimensional information; each reading corresponds to a location on a single plane.

While there are a number of software solutions for image processing, specialised to various purposes, including several options specially made for archaeological geophysical data, GEOPLOT3 (Geoscan Research 2006) was selected as the primary tool. The main reasons for this decision were that for more than half of the surveys (especially taking into account the multiple resistivity data sets where the multiplexer was used) it is the 'native' software, developed by Geoscan Research specifically for their equipment, so the instruments could be directly downloaded into the programme. It also required no investment in terms of learning a new programme inside out, and there was access to significant expertise using it in the department. As a programme specifically designed for archaeogeophysics, it has a number of data correction and processing options that would be quite hard to implement in other raster processing software. However, the publishing options are somewhat limited, so the data was exported to ArcGIS 9.1 (ESRI 2005) for the creation of figures, and to digitise the interpretation drawings.

7.2.2 Process overview

Generally speaking there are two aims to geophysical data processing, and two slightly different philosophies between them. First, it is often necessary to make corrections to the data: for example removing spikes in resistivity data (falsely high readings) caused by poor probe contacts, or staggering introduced in an incorrectly walked zig-zag gradiometry survey, where the paired readings are slightly out of step, due to different pace-lengths on the forward and back runs. It can also be necessary to compensate for unavoidable 'errors' in the data, for example, ferrous spikes and drift in gradiometer data, or mis-matched grids in resistivity survey resulting from having to move the remote probes and not getting a close background match.

Just making these minor corrections can render a dataset much more easily interpretable, and sometimes they are all that is needed. Sometimes, however, a dataset can be considerably enhanced by further processing. There is a very fine line between enhancing a dataset to the benefit of the archaeological interpretation, and introducing unnecessary processing that results in a 'pretty' image. In the latter there is a danger that misleading anomalies and features are created as a result of the processes, rather than reflecting any buried features. It is also equally possible to remove archaeologically relevant information from an image, either with correction processes or enhancement processes. Careful consideration and comparisons are needed at each stage to check for this. In the end, the resolution of archaeological information, rather than a consideration of aesthetics must be the governing principle in any data processing. Sometimes, therefore, it is best just to leave the data alone.

As a principle, and to work towards epistemic transparency, any geophysical data plot should be accompanied by a detailed account of the processes applied and the display properties used to produce it. In this work, these descriptions are located in Appendix A. This allows the process to be deconstructed, clearly demonstrating how interpretations have been arrived at.

There are two main types of process that can be applied to a raster image. Point operators transform a single cell, based on its original value, to a new value in the resulting raster. Neighbourhood operators (also called convolution) examine the values of a given region around the cell being transformed (sometimes called a

window, or kernel) and use those values to determine the value of the central cell in the new raster. Neighbourhood operators are subject to edge effects, where the kernel is cut off by the proximity of the target cell to the edge of the image; unpredictable responses can happen, or the filter may simply be programmed not to run to the edge of the image.

When one or other of these functions is calculated for each cell in the raster, a new raster image is generated with the new values (see Figure 7.2). This simple principle can be used in an almost infinite number of ways, to do very useful operations on images, such as showing regions of rapid change, or performing adaptive contrast balancing on aerial photographs, allowing greater levels of detail to be recovered from the image. The following sections will discuss common correction and enhancement filters, and will state whether they are point or neighbourhood operators, or work on some other principle.

7.2.3 Data corrections

Most geophysical surveys require some corrections to the raw data collected in the field. This can variously be due to operator errors, minor instrument problems, or inconsistencies in the survey environment. Many of the filters used for correction and enhancement use the overall statistics of the dataset as the mathematical basis for their actions, so the first port of call (other than any changes that need to be made to arrange the data correctly in the grid) is usually to remove outlying values from the image, to allow the parts of the image with the most variation to be displayed using a greater range of values. This is essentially improving the contrast of the image. In other image processing software, these might be transformations of the histograms such as a contrast stretch, or histogram equalisation process. In GEOPLOT there are two means of achieving this, either a neighbourhood operation called 'despike' or a simple clipping process which is a point operator. The despike tool allows the operator to define the shape of the kernel, in terms of the number of readings that make up the window in the x and y direction (as some surveys might have more in-line readings than traverses), and set a threshold above which the value will be discarded and replaced with the mean of the values surrounding it. The threshold is set as a number of standard deviations of the mean of the whole dataset. By changing the kernel size and the thresholds, increasingly harsh effects can be produced. The filter is a neighbourhood operator though, and does not deal well with the edge of the

image. It also does not work very well if the image has a large standard deviation; the threshold may be too low to capture all of the spikes in the image.

These problems can generally be overcome by using a point operator, (the clip function) in GEOPLOT to set a minimum and maximum value (usually determined by the image statistics, but selected by the operator). The filter examines each cell in the image, replacing those that fall outside this range with the mean value in the image. This can drastically reduce the spikes, but should be used with caution as the replacement value is the mean for the image, not the surrounding cells, and so may artificially reduce or raise some higher/lower areas of the image that reflect archaeologically interesting variations.

These despiking processes can be used in tandem, with a clip function being used to 'fix' the image statistics and remove outliers, then despike being used to reduce noise in the image. Despiking tools should always be used first, after positional corrections, as if left in place the spikes can be concentrated, smeared or otherwise enhanced by the other filters and processes, potentially resulting in misinterpretations of the data. They may be required in any type of two-dimensional survey, as spikes could result from noise introduced by the instrument, by modern material in the topsoil, or by poor probe contacts or changes in the ground surface.

Other corrections are more closely linked to the type of survey undertaken. In resistivity survey, the background resistivity values for adjacent grids may vary slightly due to the repositioning of the remote probes. This can easily be corrected with a point operation to add or subtract the required offset from all of the cells in the offending grid(s).

EM and gradiometry surveys might be subject to drift; a gradual change in the values over time resulting from systematic changes in the background (diurnal shift in gradiometer surveys) or the instrument warming or cooling (in EM surveys), that is unrelated to the actual values being detected and occurs incrementally over the grid. One solution is to use a point operator that take the change across the grid (the far edge bias) and applies an incremental increase or decrease to each value in the cell to offset the imbalance at the same rate it occurred at. For data that in theory has a

central point of 0, i.e. gradiometer data, GEOPLOT also has a specific filter that would be very hard to replicate, the 0 mean traverse. There should be very little drift over one traverse of data, and GEOPLOT understands how the data was collected, and can correctly identify traverses in the data. The zero mean traverse looks at each such run of values, and adjusts each point in the sub-set to make the mean of the traverse zero. This removes any drift in the grid, and if applied to a whole dataset, any grid mismatches as well.

In the hands of inexperienced operators, gradiometer surveys can be prone to heading errors, particularly at the start and end of lines as the surveyor makes small changes in the orientation of the gradiometer when switching it on or off, or stepping over a grid tape. These can be corrected with a simple point process where the affected values are selected (perhaps those from the first or last meter) along each grid edge, and a simple addition or subtraction employed to bring the values back in line with their close neighbours. The exact value must be chosen by the operator with careful inspection of adjacent values to determine how much the heading error has biased the reading by. They can also be subject to periodic errors caused by the gait of the operator, or perhaps a regular pattern of small height changes over a ploughed field. These can be removed by careful analysis of the frequency spectrum of the image, and filtering for specific components of the spectrum. These two corrections fall somewhere between point operators and neighbourhood operators, or use a combination of the techniques.

7.2.4 Image enhancements

Further processes may be applied to enhance the data, rather than just correct mistakes and survey problems. Typically, these might involve sharpening (high pass filters) or smoothing (low pass filters), both neighbourhood operators, to emphasise different aspects of the data. For example, resistivity data is quite often high pass filtered, which essentially preserves areas of rapid change and high contrast, and removes gradual changes. This serves to sharpen up potentially archaeological anomalies, whilst removing gradual background changes that are assumed to reflect geology-scale variations, but which are possibly swamping smaller, more localised changes. Low pass filters are often used to smooth gradiometer data, as this can be quite visually noisy, due to small scale but large changes in the readings. These can obscure archaeological features and cause problems for interpretation, so a smoothing

operation reduces the noise and makes the image easier to interpret. In both cases, in GEOPLOT the user controls the intensity of the function by dictating the shape of the kernel applied to the data, and how the kernel elements are weighted. It is in using these processes that problems can arise, either with overly smoothed data, or with data with processing artefacts that look like archaeology. It is tempting to filter data to produce a smooth output that easy to look at, but there are times when the simply corrected dataset is equally informative, or perhaps even more so. There are a number of other filtering and enhancement options, but they were not needed for this research.

7.2.5 Other processes

GEOPLOT also has a number of tools not strictly for data processing. The most commonly used is interpolation; this can either expand or reduce the dataset, and is often used to increase the readings in one direction to match the other (for example a 1 x 0.25m gradiometer interpolated twice in the y direction to a 0.25 x 0.25m survey). This works by the software inserting a new data point in between two values, taking its value from a combination of its neighbours. It significantly increases the file size and processing time, and is therefore often done in the final stages of processing as part of smoothing the image. Care must be taken to avoid introducing processing artefacts by this method, and smearing noise or spikes into apparent features. The process can also be used in reverse, to de-sample a survey, to allow direct comparison with another technique, or to combine two surveys collected at different reading intervals.

It is also possible to use selective filters to separate out areas of high and low resistivity, or positive and negative gradiometer responses according to user set thresholds, or generate contour plots of the data.

7.3 Ground penetrating radar

7.3.1 Introduction

The nature of GPR survey means that large volumes of data are collected and then analysed, especially when conducting area surveys with the intention of producing horizontal time-slices, as in this instance. The individual radargrams were not studied in great detail, or processed prior to the timeslicing as for this research, simple

timeslicing, as outlined below has proven effective. This three dimensional approach to the data was necessary due to the nature of the peat landscapes and multi-layered archaeology expected on the sites, particularly in the lowlands.

7.3.2 Timeslicing

Producing timeslices is a complex task with many stages. Timeslicing produces a number of plan views of the radar amplitudes at regular pseudo-depths through the collected profiles. The software used, GPR-SLICE (Goodman 2008) uses a subjective gain curve that is determined by the user visually and as such does not have a 'value' that can be reproduced in the Appendix (A) on data manipulation. The gain-curves used in the processing are retained with the dataset however to allow re-processing under the same parameters if needed.

The data is downloaded from the tablet as raw radargrams and imported into GPR-SLICE. The data is then converted which involves re-sampling the data to 32 in-line samples/m. The radargrams are then arranged in a Grid and where appropriate (as in the case of zig-zag survey) the readings in selected lines are reversed. Horizontal grids of data are then built from the data in the profiles. This is then interpolated into timeslices. The thickness, in terms of the time window averaged in the image, of the slices is decided by the operator. Unless otherwise stated the timeslices presented are the squared amplitude of the values for that particular stack of samples within the grid.

Once the slices have been created, they can be processed in ways similar to two-dimensional surveys such as low and high pass filtering, and histogram adjustments to correct the contrast of the images. One important function allows all of the images in any created dataset to all be displayed to the same histogram, meaning a particular shade represents the same squared amplitude in all of the slices, and the intensity of anomalies is preserved relative to each other in all of the images, rather than each image using its own greyscale.

7.3.3. Mosaic corrections

There are mosaic errors, that is, zones with different background signal responses and anomaly strengths (Ernenwein & Kvamme 2008; Goodman 2008, Sections XV.A & E) in some of the radar datasets caused by the survey being done on a number of different dates, sometimes weeks apart and therefore under different conditions. A

number of the suggested processes for dealing with these have been attempted, and the most satisfying result has come from applying a filter at the stage immediately after slicing the data, but before producing any gridded datasets, that creates a zero mean for each line of data. This function has a threshold based on a certain percent of the values in a line. The most satisfactory results have been with it set to ignore the top 50% of all of the values when calculating the average. This means anomalies (and especially linear anomalies in the survey direction) are more likely to be preserved, and a better background match achieved. It is similar to the zero mean traverse function used in GEOPLOT to correct for drift. This has not totally removed the mosaic problems within the dataset, but is comparable, in terms of the visible anomalies as processing each block of readings collected on the same day separately, which was done for one of the datasets to make a comparison between the two techniques for dealing with this common problem.

7.4 Electrical resistance tomography

7.4.1 Introduction

In theory, the active sensing depth of a resistivity array is in part a function of the probe separation (see Section 2, Chapter 5). As the probes are further separated, the volume of soil examined increases, as does the depth at which the array is most sensitive to changes. However, it is not as simple as being able to state that a 1m array will give the resistivity of the ground 1m below the centre of the array; the current is passing through the whole volume of the soil. Corrections must also be made for the array dimensions (conversion to apparent resistivity). To more accurately interpret resistivity data collected over various depths, a mathematical modelling process needs be undertaken on the data which attempts to take into account the characteristics of the soil over the whole profile, from the field measurements, to more accurately interpret the extent and intensity of any variations.

This requires the measurements of resistivity along a transect, with increasing probe separations along the transect. Specific hardware solutions exists for these resistivity profiles, and they have been commonly employed in geological and engineering geophysics for some time, and are increasingly being used on archaeological sites. They usually consist of a number of electrodes (normally 20+) which are arranged along a transect, or in a grid, for three dimensional measurements, and a control unit,

which automatically switches between electrodes, taking a series of measurements across the array at expanding probe separations (see Figure 7.3).

This research used a slightly different approach; on the lowland sites multiplexed resistivity survey had been employed to give six different twin probe separations, each showing a plan view of a different pseudo-depth. In essence, each survey grid was made up of 20 ERT transects, with six readings with separations of 0.25, 0.5, 0.75, 1, 1.25 and 1.5m at 20 points along the transect. This is contrast to the usual method of an expanding set of readings starting at 1m and the widest being 20m being taken by 20 electrodes on that line. Our surveys had perhaps therefore had less depth information, but were more detailed in their coverage. With some modifications, it was possible to use this data in a common resistivity inversion programme, Res2DInv (Loke 2005).

7.4.2 Data capture and pre-processing

The data needed some modifications prior to being imported into Res2DInv and analysed. The data had already been downloaded and assembled in GEOPLOT3 and processed as plan view two-dimensional resistivity data. The raw field data were exported as xyz files and opened in a spreadsheet where they were converted to apparent resistivity. For some of the data analysed this way, some extra changes were made as the data contained many values close to zero, or negative values, which caused the algorithm to fail. The negative values were removed and replaced with the mean, as were obvious outliers caused by poor probe contacts. For the dataset containing values close to zero, the data were then multiplied by ten. This is documented fully in Appendix A.

7.4.3 Data inversions

The inversions process is mathematically complex, and there are ongoing debates about the best equation parameters to use. In summary, the program, Res2Dinv, (Loke 2005) takes a transect of measured values (after conversion to apparent resistivity) and builds a sub-surface model that could have produced those readings at the probes. It then simulates a survey over that model and compares the result to the observed data. It then re-builds the model and repeats the process, refining the results towards the field data over a number of iterations. Thus three images are presented; the observed data, the best model of it and the simulated survey over that model. The

accuracy of the model is described by a measure of the Root Mean Squared error (RMS error) between the simulated dataset and the field dataset. The model is a 'best guess' as to the true spatial extent and intensity of the differing resistive materials in the sub-surface.

There are several different options with the program that control how the model is built (the size of the model cells for example) and how the equations are applied. The best results for this survey method were obtained by forcing the model blocks to be ½ the unit spacing (1m, the sample interval). The smoothing or robustness constraints to the model were applied depending on the best results for the particular site being investigated; these are discussed fully in Appendix A.

7.5 Data display

7.5.1. Introduction

Wherever possible, the geophysical data was worked with and presented as greyscale images. This follows best practice guidelines from English Heritage (2008) as colour displays can be confusing when representing univariate data.

7.5.2 Two-dimensional techniques

For all the of the datasets that were processed in GEOPLOT the data is presented as a greyscale with a palette of 55 shades of grey, about the mean, over +/- 3 standard deviations (SD). The image display properties may have variously been adjusted (for example to absolute values, or to a 'tighter' display about the mean) to better examine the details of some parts of the image where localised contrast enhancement was needed; if the image is manipulated in this way, the figure will clearly state this.

7.5.2 GPR timeslices

All timeslices are shown with scales produced by the software and with added North arrows. The plotting parameters are a black and white linear scale with the raster cell value describing the colour intensity. The raster cell values are the squared amplitude for the slice and black is the highest value, white lowest. The scale has been normalised across all of the timeslices in a particular dataset, and so may vary between them.

7.5.3 Electrical resistivity tomography

The software derives values for each block of the model. A plot of the model blocks (and their sensitivities to small local changes; this is a problem at the edges of the model) are presented with each set of data plots. The software then plots contours at logarithmic intervals of apparent resistivity and shades them, with hotter colours representing higher resistances. It was not possible use a greyscale output. The scale is displayed on each set of inversions, and is unique to each inversion plot. It should be noted that the values for resistivity given in some of the legends are not always correct; some of the data had to be increased by an order of magnitude as the inversion fails where there are values close to zero, due to software limitations.

Chapter 8: Ground-truthing principles

This short Chapter sets out the guiding principles for the ground-truthing work that took place on selected case study sites. The specific techniques and aims are recounted in the relevant chapters in the following section. What follows here is a short discussion of the need for ground-truthing of geophysical surveys in general, and the principles adopted in out approach.

8.1 The need for ground-truthing

Discussion of ground-truthing the results of remote sensing and geophysical survey seems somewhat lacking in the current UK literature, with one or two notable exceptions (Jordan 2009), and this is highlighted as a problem of commercial surveys being undertaken separate from the excavations they are designed to support, with little feedback (Gaffney & Gater 2003, 182) to help the geophysicist develop and improve interpretations and understanding. In North America, perhaps because the discipline there is much younger and in some ways is struggling for acceptance from the wider archaeological community, there seems to be much more of an emphasis on testing survey interpretations by excavation or other means (Hargrave 2006; Johnson & Haley 2006). This is also linked to the rather more positivist paradigm, rather than interpretative thinking in Europe. There are very strong arguments for conducting ground-truthing work following surveys. Without this process, we have no way of evaluating our interpretations of the results, and nothing to inform or challenge our future interpretations on similar sites. The feedback loop of survey, interpretation, excavation, re-interpretation, survey, then interpretation based on lessons previously learned needs good communication between surveyors and excavators, and needs a good understanding of archaeology on the part of the surveyor; something that is not always the case in commercial work.

One area English Heritage has explicitly called for more ground-truthing of surveys is in GPR surveys over wooden remains in peatland and wetland environments. Without checking our interpretation of anomalies considered to be waterlogged wood, we have no idea whether we should press on with developing this area of GPR application. Given the strong differences between peatland sites and others that are relatively well

known, we do not have adequate comparison sites to draw conclusions and interpretations from. Thus, ground-truthing new surveys in these environments should be regarded as a priority, not just for this project, but for the foreseeable future, even though peatlands pose challenges to ground-truthing.

8.2 Ground-truthing principles

In some ways, the ideal approach to ground-truthing a survey would be the total area excavation of the survey area to check what the survey located, and if the interpretations match, but also if the survey missed anything. In practice, this is rarely possible, apart from in development/rescue situations. What more often happens is that a number of promising targets are investigated based on the geophysical surveys; the 'Time Team' approach, familiar to so many in the UK. Where excavations are not possible, there might be a chance to use borehole survey to test the interpretation of the sedimentary units identified in the surveys, or trial trenching rather than full scale excavations.

In peatland environments, the usual problems of excavation are magnified by the nature of the deposits. They are waterlogged, and in the lowlands, potentially full of very fragile archaeological material; so excavation is painstaking, and expensive, with high follow up costs in terms of conserving significant recovered finds. Upland sites are potentially easier to physically excavate, but have problems to do with site access, their exposed location, and the quality of preservation. Furthermore, many peatlands have now been protected in their own right, under the Ramsar convention, or as AONB, SSSI or parts of National Parks or National Nature Reserves (see Section 2.4). The environments are frequently highly sensitive to disturbances, so ground-truthing operations need to mitigate for this as much as possible, and comply with any rules set down in the protective legislation. With these factors in mind, the following general principles were adopted for the ground-truthing elements of this project.

Any ground-truthing work for this research project should meet these principles, so as to assist in the conservation of the archaeology under investigation and the peatland environments that have protected it for so long.

- Interventions should be the minimum possible to deal with the research question posed; if coring will provide the information needed rather than excavation, opt for the least invasive option
- All interventions should have a specific purpose - no speculative excavations, though there might be a need to obtain control data from geophysically 'quiet' parts of sites
- These questions should be closely linked to the original aims of the individual case study project, and the overall aim of the research as a whole
- Where interventions are permitted, the maximum amount of archaeological information should be sought and recovered. For example, if monoliths are to be taken through a peat sequence, even though palynology is not within the scope of this project, the monolith should be offered to interested parties to maximise the information retrieved from any excavation or boring
- The results of the ground-truthing work and surveys should be disseminated as widely as possible so that comperanda become available to other researchers in this, or related fields

The specific application of these principles to ground-truthing is discussed in the relevant chapters in Section Four.

Section Four: Case Studies

This section has a chapter dedicated to each of the separate case study areas, and is split into three parts. The first two chapters (9 and 10) deal with lowland environments, the second two with upland environments (11 and 12).

Each of the Chapters follows the same format, based on the English Heritage guidelines for reporting on geophysical survey (English Heritage 2008). Commencing with a general overview of the area, the archaeology and the reasons for its selection for the project, the Chapters then deal with each specific survey site as a separate entity. For each site, the specific site background is examined, and the individual survey aims outlined. This is followed by a brief discussion of the specific geophysical methods employed on site, including survey methodology and instrument settings. The data processing details are not included in the main text, but are presented in Appendix A, as discussed above. For each survey technique, the results of each technique are presented separately, with a synthesised interpretation following. Conclusions specific to the case study are presented. Following the presentation of both sites within a case study area, a general evaluation of the performance of the survey techniques in that area is given, and where carried out, this is followed by a presentation of the aims, methods, results, interpretations and implications of any ground-truthing work carried out.

Chapter 9: The Sweet Track, Somerset

Two separate surveys were conducted over this important monument in the Somerset Levels, each found on a different part of the landscape with different characteristics, Canada Farm, and The Old Peat Works. The site specific differences will be discussed in the relevant sections below (9.1.1 and 9.2.1): this introductory section will describe the archaeology and general history of the monument.

The Sweet Track was discovered in 1970 during commercial peat cutting, not far from the sites we eventually chose to survey (Coles & Orme 1976a). There had already been tracks discovered in the levels, and archaeologists and the peat companies alike had become alert to signs of them. The Sweet Track was to prove to be the earliest of them all; dendrochronology now places the felling of most of the timbers in 3807 or early 3806 BC. It was a single plank walkway, laid across the wetter part of a wet reed swamp. Subsequent growth of the peat and further inundation have preserved the trackway in remarkable detail; the state of preservation of the timbers is so good that archaeologists have been able to discover new aspects of prehistoric woodworking and forest management. It is the oldest securely dated track in Britain, and is unique in its construction (Coles & Orme 1976a; Coles & Coles 1986).

The Sweet Track also relatively well understood and its main features documented. Over 12 years, as part of the Somerset Levels Project (SLP), portions of the trackway were excavated ahead of commercial peat extraction and drainage of the works (Coles & Orme 1976b; Coles & Coles 1986). In places, where the track has not been excavated, its presence has been confirmed by inspection trenches and coring; and at Shapwick Heath Nature Reserve, the old peat workings have been re-flooded to encourage the return of mire vegetation and preserve the remaining timbers in-situ (Coles 1996) (see Figure 9.1).

The Sweet Track therefore made an excellent case study site, as we could be confident of the location, form and depth of the archaeological remains prior to survey, or so we thought. It was initially assumed that we would be able to ground-truth the surveys by recourse to the written records of the SLP, rather than disturb such a sensitive environment. There had also already been a successful geophysical survey of

the monument by Utsi in 2001; a GPR survey that claimed to have located the trackway, though with some problems of lateral resolution of the exact line of the monument (Utsi Electronics 2001).

9.1 Canada Farm

9.1.1 Site background

This survey took place over a preserved, re-wetted section of the trackway not far north of the original discovery site. The survey Grid was located adjacent to the previous GPR survey in 2001. See Figure 9.1 for a location map and Figure 9.2 for a generalised profile of the peat and other sediments in this part of the Brue Valley. The site is protected as a Scheduled Monument, and since the successful restoration of mire vegetation, as an SSSI, a National Nature Reserve, and internationally protected as a Ramsar wetland.

9.1.2 Survey aims

Unlike the other case study sites, this particular survey did not have any specific archaeological research objective save those of the present research project. It was felt at the start of this work that the site was relatively well understood and as such would provide a useful testing ground in which to compare the responses of the four selected geophysical techniques.

9.1.3 Methods and instrument settings

The work was conducted on various dates between 12 November 2007 and 2 December 2007. The period was generally wet, with rain falling during some of the work. The site had surface water for the duration of the work.

The grid was located over on the known position of the trackway (from HER data and the records of the Somerset Levels Project) relative to current field boundaries. The grid was established with reference to these, and then georeferenced and recorded with dGPS to allow the results to be georectified in a GIS package and compared back to the HER data. One 20 x 20m grid was surveyed with all four techniques. The survey transects were oriented to cross the line of the trackway at 90 degrees in order to maximise the response.

The gradiometer, resistivity and EM instruments were not expected to have a great response, as discussed in Chapter 4, but were included to allow a more complete assessment of their use in conjunction with other methods. Two different radar frequencies were tested in the field to enable comparisons to be made with regard to depth of signal penetration and the resolution of each antenna. From trial surveys the 250 MHz antenna was selected as giving the best response.

Table 5: Instrumentation employed at Canada Farm

Survey type	Instrument	Accessories/notes
Resistivity (inc. Tomography)	Geoscan Research RM15(A) with MPx15	Used with a linear six probe array to allow simultaneous measurements of six different twin probe separations (.25, .5, .75, 1, 1.25 and 1.5m).
Magnetometry (gradiometer)	Geoscan Research FM36	Used in preference to the Bartington DualGrad 601 (despite the latter's' greater depth penetration) due to the greater manoeuvrability of the smaller instrument in such long vegetation.
Electro-Magnetic	Geonics EM38B	Used in both Horizontal and Vertical modes to compare depths of any detected features. Both inphase and quadrature components of the response logged.
Ground Penetrating Radar	Mala RAMAC GPR	Both 250 MHz and 500 MHz antennae employed to test signal penetration in thick peat soil. 100 MHz survey wheel used to measure distances.

Table 6: Instrument settings and survey methods at Canada Farm

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
RM15 with MPX15	1m	1m (six readings for each probe sep. at each point)	Zig-Zag (but preserving array geometry)	0.5 ohm resolution.
FM36	0.5m	0.5m	Parallel	0.1 nT resolution
Mala RAMAC 250MHz	0.5m	0.05m	Zig-Zag	65 ns time window. 580 samples. Presumed velocity of 0.08m/ns
Mala RAMAC 500 MHz	0.5m	0.05m	Trial runs	67 ns time window. 512 samples. Presumed velocity of 0.08m/ns
EM38B	1m	1m	Zig-Zag	Both inphase and quadrature responses logged, and surveys completed in both horizontal and vertical modes.

Once collected and downloaded the data were processed in GEOPLOT and GPR-SLICE as appropriate. The resistivity data was also exported from GEOPLOT and modified for use in Res2DInv to produce electrical resistance tomography profiles. For a detailed log of the corrections and enhancements applied, please see Appendix A.1.

9.1.4 Results and interpretations

The data are plotted as Figures 9.3 to 9.38. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs, where appropriate. The interpretation plots were then digitised from the rectified data plots.

Description

RM15/MPX resistivity survey

Probe Separation A- Figure 9.3

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 17 ohms to around 30 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge.

Probe Separation B- Figure 9.4.

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 9 ohms to around 15 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge.

Probe Separation C- Figure 9.5.

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 6 ohms to around 10 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge. This is particularly strong in the northern side of the grid.

Probe Separation D- Figure 9.6

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 5 ohms to around 7 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge. This anomaly is now intense enough to be visible prior to high pass filtering.

Probe Separation E- Figure 9.7

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 5 ohms to around 6 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge. Once again this anomaly is visible prior to the high pass filtering.

Probe Separation F- Figure 9.8

Prior to high pass filtering this plot shows a gradient in resistivity from low resistance on the western edge of the grid to higher resistance at the eastern one, from roughly 3.5 ohms to around 4.5 ohms (not converted to apparent resistivity). Once the gradient had been removed, two areas of higher resistance are visible, along the northern and southern edges of the grid, about 5m in diameter (but cut in each case by the edge of the grid), and about 5m in from the eastern edge. The northern of the two anomalies is slightly more extensive and intense. There is a linear run, about 2m wide, running north/south of lower resistance readings, starting 16m in from the western edge. Once again this anomaly is visible prior to the high pass filtering.

FM36 Survey- Figure 9.9

The unprocessed data has a very narrow band of responses (from -7.5nT to +4.5nT) and this includes some very strong 'spikes'. Once these have been removed there are two anomalies of note in an otherwise very quiet background. There is a faint band, roughly 1m wide of reduced response, appearing as a linear anomaly running north-south through the grid roughly 14m from the western edge. This is orthogonal to the survey direction and so is not a surveying error. There is an area of strong (comparatively) enhanced response (2nT above the background) in the south east corner. This anomaly starts 1.5m in from the eastern edge and continues to the eastern edge. It is roughly 1m wide and runs from the southern edge up to roughly 7m into the Grid, or 13m from the northern edge.

EM38 Survey

Vertical quadrature phase response- Figure 9.10

The plot shows a gradient from high to low conductivity from the western to eastern edge of the grid; roughly 35mS/m down to around 25mS/m. There is a clear 2m/reading wide higher conductivity anomaly running north-south in the grid 3m in from the eastern edge and 16m in from the western edge.

Vertical inphase response- Figure 9.10

This plot shows a very narrow range of readings; between 0.1 and -0.1 SI for the most part. There is some variation or trend from the north to the south of the Grid, with the

north showing marginally higher magnetic susceptibility but this could be due to drift within the instrument as the variation is very small.

Horizontal quadrature phase response- Figure 9.11

The plot shows a gradient from high to low conductivity from the western to eastern edge of the Grid; roughly 40mS/m down to around 30mS/m. There is a clear 2m/reading wide higher conductivity anomaly running north-south in the Grid 3m in from the eastern edge and 16m in from the western edge.

Horizontal inphase response- Figure 9.11

This plot shows a very narrow range of readings; between 0.1 and -0.1 SI for the most part. There is some variation or trend from the north to the south of the Grid, with the north showing marginally higher magnetic susceptibility but this could be due to drift within the instrument as the variation is very small.

GPR 250 MHz Survey

30 timeslices were produced from the radar data of the first 39ns/1.37m of the response; below this the signal became too attenuated to draw useful conclusions. Figure 9.12 gives depth estimates for each timeslice, which are then presented as Figures 9.13 to 9.26; here the anomalies are discussed more generally in terms of their extent in 3 dimensions.

In the upper part of the results (0-10ns/ 0- 0.35m, slices 1-7) there are some high amplitude responses in the southern part of the grid, some of which seem to lie along the same area as a linear anomaly visible at greater depths. From this point there is a consistent band of higher amplitude responses along the northern edge of the grid. From about 10ns/ 0.35m (slices 9-21) to 28ns/0.98m there are three significant anomalies. In the south west quadrant of the grid a strong dendritic anomaly appears; this is a large anomaly roughly 10m x 8m at its greatest extents. There is a linear change in amplitude running north south through the grid roughly 16m in from the western edge that, over depth, resolves to be a slightly higher amplitude anomaly At its greatest extent it is 1.5m wide. It is somewhat irregular but visible in 8 slices, disappearing at 22ns/0.76m (Timeslice 16). At about this depth the general trend towards higher amplitudes along the northern edge of the grid increases markedly in

the north east corner of the grid with a number of high amplitude responses clustering in the same part of the grid. This continues to the final slice but the area is interrupted or cut by an area of low amplitude roughly in the same position as the linear anomaly; running north-south and at roughly 16m in from the western edge of the grid.

Resistivity inversions

All ten inversion profiles are presented as Figures 9.29 to 9.39. The sensitivity and blocks of the model used are presented as Figure 9.28.

Profiles 1-5 run north-south across the grid and profiles 6-10 run west-east across the grid. Figure 9.27 shows the location of each profile along the grid edges.

Profile 1- Figure 9.29

This profile shows a general decrease in resistivity with depth. At the immediate surface between 6.5m and 12.5m there is a thin band of lower resistance values. There is a significant high resistance anomaly running from 12m to 19m along the profile and from the surface to about 0.75m deep.

Profile 2- Figure 9.30

This profile shows a higher surface resistance than profile 1 in both relative and absolute terms; resistances are generally higher and the highest resistance areas are more extensive. The resistance decreases sharply with depth after 0.75m. There is an interruption in this band of higher resistivity between 8.5m and 12m that extends over the entire depth of the profile.

Profile 3- Figure 9.31

This profile shows a general decrease in resistivity with depth. There a band of higher resistance from the surface to about 0.6m deep across the whole profile apart from a small gap between 8.5 and 12m. There are two areas of significantly higher resistance within this band. The first and most intense is from 0.25m to 5.25m and seems to have two 'hotspots' within it. It is present from the surface to about 0.5m depth. The second is much smaller and less pronounced. It runs from 18m to 18.5m along the profile and from 0.2m to 0.4m depth.

Profile 4- Figure 9.32

This profile shows a strong band of higher resistance values, in absolute terms; the values are generally higher than in profiles 1 & 2. They also carry on to greater depth than in the other profiles, continuing down to about 0.8m. The peak values are expressed more consistently and over a greater area; running from 0.25m to 8.25m and to 0.5m depth from the surface. They then continue more intermittently but still in this focused band to the end of the profile.

Profile 5- Figure 9.33

This profile shows a band of intermittent very high resistance readings (by comparison with the other profiles) across the length of the profile, starting at about 0.2m down and continuing to about 0.75m.

Profile 6- Figure 9.34

This profile (the first of the west-east ones) shows that to the start of the survey line there is very low resistance, right the way to the surface. The profile is split diagonally in two by a marked change in resistivities; at the surface this starts at roughly 5m but is stronger from roughly 8m. The line of the change slopes gradually to meet the bottom of the profile at roughly 12m. The zone of higher resistance reduces with depth, reaching similar values to the first part of the profile at between 0.75m and 1m depth. There is a slight break in the higher resistance values at roughly 16m along the profile.

Profile 7- Figure 9.35

This profile shows very similar properties to profile 6.

Profile 8- Figure 9.36

The first 6m of this profile show very low resistance measurements all the way to the surface. Rather than the diagonal split observed in the preceding two profiles this profile has a consolidated band of higher resistances from about 8m to the end of the profile, with the last 4m being markedly more intense. This band runs from the surface to about 0.5m deep.

Profile 9- Figure 9.37

This profile shows a similar pattern to 6 &7, with a sloping edge between a higher resistance zone and a lower one. The higher resistance zone starts at the surface at about 4m, though it is quite intermittent to about 10m. There is a gradually sloping edge that meets the bottom of the profile at 14m. There is a slight reduction in the intensity of the high resistance zone at 16m. The high resistance zone is generally much strong to about 0.6m depth for the last 5m of the profile.

Profile 10- Figure 9.38

This profile shows a coherent zone of higher resistance from about 8m along the profile to the end and from the surface to about 0.75m deep. It is preceded by an area of much lower resistance running all the way to the top of the profile. Below 0.75m in the whole profile the resistivity decreases.

Interpretation

Numbers in the text refer to features identified in Figure 9.39.

Consistently across all of the datasets there is a linear anomaly running north/south 16m eastwards of from the western edge of the grid (1). This corresponds to the known location of the Sweet Track. It appears as a low resistance/ high conductivity anomaly and appears to have some influence on the magnetic response as well, though this does not correspond directly to the track's location. Though the resistivity inversions do not show it clearly, there is a trend for higher resistances at the eastern side of the grid (2 & 3), and in a number of the profiles there is a disruption to that at the 16m mark. The radar data shows a slight change in amplitudes at the correct depth and lateral position of the trackway and the anomaly is the right width; this closely matches the results of the resistance based surveys. The trackway has already been located in this area by GPR survey (Utsi Electronics 2001). The radar also revealed something not seen in the other surveys; the large dendritic anomaly (4) is almost certainly a bog oak. There are several eroding out of the peat at the nearby Peat Works site (now pasture) and they are of a similar size. The low magnetic variations on the site were expected (Thompson & Oldfield 1986; Weston 2004) so the presence of a linear anomaly (5) apparently related to the trackway needs further investigation.

Furthermore, though the resistivity surveys picked up the trackway in the same location that the radar did, the bog oak was not seen in the responses.

There is a clear change in the electrical character of the subsurface moving west-east across the survey grid.

9.1.5 Case-study specific conclusions

An anomaly in the correct location was detected by all of the instruments at the Canada Farm site. However, on closer examination it seems that only the GPR was directly responding to the trackway. The electrical data shows an anomaly in the location of the track, but not the bog oak, whereas the radar shows both. If they were responding to the same physical properties of the wood, the bog oak should also show in the EM and RM15 data. There is also a gradient in the resistivity of the peat, and a common depth to the changes. This common depth is around 0.75m from the surface; the same depth as the trackway in that location (Coles & Orme 1976a; Coles & Coles 1986; Utsi Electronics 2001), and the same depth at which the 2001 survey claimed to have detected the trackway timbers. The track was built on a semi-stable surface in the peat and was later subsumed so it is possible this reflects a change in the type or physical and chemical properties of the peat itself. The gradient could also be as a result of this, or of different ground water bodies.

The reasons for the trackway showing like this, especially in the magnetometer data are not clear. The current working hypothesis is that the track itself is influencing the hydrology within the peat causing the loss or collection of minerals within the pore water and peat matrix, and it is these variations that are being detected. Further work was carried out on the site to sample the water and peat and conduct chemical analyses to determine if there is a variation in the chemical composition that reflects the changes shown in the geophysical data. This is reported in Section 9.4.

The detection of the trackway at the Canada Farm site by GPR confirms the earlier survey (Utsi Electronics 2001) and bodes well for more consistent detection of waterlogged wood in active peat more generally. The totally unexpected detection of the track (albeit not directly) with the EM, resistivity and gradiometry surveys raises a new set of questions about what properties of the archaeology and sediments are interacting to produce those responses. The spectacular bog oak shown in the GPR

results from Canada Farm shows the potential of GPR as a prospecting tool for more substantial wooden targets in peat. Figure 9.40 is a photograph of an emerging bog oak, appearing as the peat desiccates about 100m west of the Old Peat Works survey area.

9.2 The Old Peat Works

9.2.1 Site background

This grid (see Figure 9.1) was situated over the known line of the trackway, where it makes landfall on a 'burtle' (local term for a sandy ridge that would have been an island of dry land in the wetter conditions). The presence of the track in this location had previously been confirmed by excavation but the site falls outside the area re-wetted following commercial peat extraction, and is now drained and used as grazing for cattle. The site is part of the SSSI but is rated as being in an 'unfavourable and degrading' condition (Natural England 2009). This was confirmed by staff at the NNR and by direct observation of bog oaks eroding out of the peat as it shrinks due to ongoing groundwater loss (see Figure 9.40). Anecdotal information from the tenant farmer suggested that flint finds are common in rabbit burrows on the burtle itself indicating use in prehistory.

9.2.2 Survey aims

Unlike the other case study sites, this particular survey did not have any specific archaeological research objective save those of the overall project. It was felt at the start of this work that the site was relatively well understood and as such would provide a useful testing ground in which to compare the responses of the four selected geophysical techniques.

9.2.3 Methods and instrument settings

See section 9.1.3 above; surveys on this grid followed the same methodology, with the omission of the trials of the 500MHz GPR antenna.

Once collected and downloaded the data were processed in GEOPLOT and GPR-SLICE as appropriate. For a detailed log of the corrections and enhancements applied, please see Appendix A.1.

9.2.4 Results and interpretations

For the data plots, see Figures 9.41 to 9.66. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs. The interpretation plots were then digitised from the rectified data plots.

Results
RM15/MPX resistivity survey
Probe Separation A- Figure 9.41
The results show one anomaly, an area of slightly higher resistance midway along the southern edge of the grid, semicircular in shape with the grid edge forming the straight side. At its maximum extent it is 4m in diameter. There is an area of reduced resistivity immediately to the west of this anomaly that is roughly 2m in diameter.

Probe Separation B- Figure 9.42
The results show one anomaly, an area of higher resistance midway along the southern edge of the grid, semicircular in shape with the grid edge forming the straight side. At its maximum extent it is 5m wide and 10m along the grid edge. There is an area of reduced resistivity immediately to the west of this anomaly that is roughly 2m in diameter.

Probe Separation C- Figure 9.43
The results show one anomaly, an area of higher resistance midway along the southern edge of the grid, semicircular in shape with the grid edge forming the straight side. At its maximum extent it is 5m wide and 8m along the grid edge. The eastern part of the anomaly is less resistive. There is an area of reduced resistivity immediately to the west of this anomaly that is roughly 2m in diameter.

Probe Separation D- Figure 9.44
At this separation the previously mentioned anomaly becomes more amorphous; the south eastern quadrant has a generally higher resistance with a more intense anomaly within this, roughly at the mid point of the southern edge of the grid. This anomaly is roughly 4m across in both directions. The low resistance anomaly is no longer visible.

Probe Separation E- Figure 9.45

The south eastern quadrant has a generally higher resistance with a more intense anomaly within this, roughly at the mid point of the southern edge of the grid. This anomaly is roughly 3m across in both directions.

Probe Separation F- Figure 9.46

The south eastern quadrant has a generally higher resistance with a more intense anomaly within this, roughly at the mid point of the southern edge of the grid. This anomaly is roughly 2m across in both directions.

FM36 Survey- Figure 9.47

This survey was affected by the presence of a metal fence at the eastern edge of the Grid. There are a number of strong ferrous spikes that could not be completely eliminated in the data processing. Aside from these, there are two anomalies of note. First is a faint linear band of enhanced response in the northeast quadrant of the grid, running northwest to southeast from the mid point of the northern edge of the grid. There is also a discrete unipolar (positive) anomaly at the mid point of the southern edge of the grid about 1.5m in from the grid edge. This is 3.5nT stronger than the surrounding readings and is only about 0.5m in diameter.

EM38 Survey

Vertical quadrature phase response- Figure 9.48

The results show an area of decreased conductivity at the mid point of the southern edge, semi circular in shape and roughly 10m in diameter. There is a small area of increased conductivity in the south west corner of the grid and another at the north eastern edge of the data not removed during processing. This starts about 2m in from the northern edge of the grid and continues for about 5m, and is 3m wide.

Vertical inphase response- Figure 9.49

There seems to be very little variation in the magnetic susceptibility of the soil on this site; what variation there is in the results does not seem to have a pattern or spatial organisation.

Horizontal quadrature phase response- Figure 9.50

The results show an area of decreased conductivity at the mid point of the southern edge, semi circular in shape and roughly 10m in diameter. There is a small area of increased conductivity in the south west corner of the grid and another at the north eastern edge of the data not removed during processing. This starts about 2m in from the northern edge of the grid and continues for about 5m, and is 3m wide.

Horizontal inphase response- Figure 9.51

There seems to be very little variation in the magnetic susceptibility of the soil on this site; what variation there is in the results does not seem to have a pattern or spatial organisation.

GPR 250Mhz Survey

Thirty timeslices were produced from the radar data of 119ns/ 4.2m of the response. These slices are 'thicker' than the Canada Farm data as the signal penetration was better but there were fewer features or anomalies to try to resolve. Figure 9.52 shows the estimated depths for each slice. The timeslices are presented as Figures 9.53 to 9.66; here the anomalies are discussed more generally in terms of their extent in 3 dimensions.

The first 5 slices (0-28ns/0.82m) show an area of high amplitudes in the northwest and southwest quadrants of the grid, with an area of reduced amplitude that grows in extent starting in the north east corner of the grid and running diagonally northeast to southwest for about 10m. By slice 5 (28ns/0.82m) the area of higher amplitudes in the western half of the grid has broken up and become unconsolidated. In slices 6-9 (19-43ns/0.7-1.38m) there is a zone of unconsolidated higher amplitude responses in the northern part of the grid, extending into the grid about 6m, for the whole of the width of the grid. There is also a more discrete area of higher amplitude signals (that becomes smaller and increasingly isolated and discrete with depth) at the mid point of the southern edge of the grid. The zone of generally higher amplitude responses in the northern 5-6m of the grid continues through all the depths but from slice 10 onwards (47ns/1.4m) the rest of the grid is speckled with higher amplitude responses that show a linear trend in the same direction as the survey; these appear to be antenna noise.

Interpretation

Numbers in the text refer to anomalies marked in Figure 9.67

The anomalies noted in the data seem to largely be geological and related to the topographic changes as the land surface moves up onto the 'burtle', a bank of sand and gravel that sits about 5m above the surrounding peat. There is one feature that appears in all of the surveys to some extent; an area of higher resistance and showing as a higher amplitude reflection in the GPR (6) midway along the southern grid edge. This has a small associated unipolar magnetic anomaly (7) and an area of lower resistance immediately to the west (8). The tenant farmer and Natural England reserve staff stated that on the burtle it is quite common to find lithics; it is therefore suggested that this anomaly might represent some sort of occupation with a compacted floor, associated magnetic enhancement from localised burning and perhaps a pit to the west. The anomaly was bisected by the edge of the grid so it is difficult to make a strong interpretation. The Sweet Track was not visible in any of the data.

9.2.5 Case-study specific conclusions

Although the trackway was not detected at the Peat Works site, a collection of anomalies on the Burtle were detected that might be anthropogenic.

An anomaly interpreted as The Sweet Track was detected at the Canada Farm site, but not at the old Peat Works. There are a number of explanations for the failure at the Peat Works site. It is possible that the track has desiccated to the point that it essentially no longer exists in the subsurface. It is also possible the track was not in the survey Grid as the SMR mapping (see Figure 9.67) shows it running next to the fence line, whereas the mapping from the Somerset Levels project (Figure 9.1, inset) shows it to be a few meters inside the enclosed land. The SLP mapping also suggests it stops at the Burtle but the SMR data has a project line of the trackway continuing on the same alignment to the end of the field. The location of the trackway at the Canada Farm site is much more certain.

9.3 Evaluation of techniques

Despite not detecting the trackway at the Peat Works site, the aims of the surveys were fully met. A negative result in a geophysical survey does not mean the survey was not successful, especially when the main aim of the work is to test the capability of the various techniques in these environments.

The results at the Canada Farm site were unexpected; in theory the trackway should not have been visible to the electrical or magnetic techniques at all, based on previous negative results at Fiskerton (Martin 2002). In this respect the degree of expected success was exceeded. The GPR results obtained in this survey do not agree totally with the 2001 surveys; they located a number of anomalous reflections in the radargrams in the correct location of the trackway, and at a depth of around 0.75m; this, the report states is the depth of the trackway in the survey area. They used a radar velocity of 0.045m/ns whereas we assumed 0.07m/ns based on the velocity in water vs. loamy soils, and the estimates used by English Heritage at Fiskerton (Linford 2003). Our depth estimates for the trackway are about 0.15-0.3m higher up the profile than those in the 2001 survey, and given the differences in velocity this could be increased if laboratory measurements of the dielectric permittivity of the peat show we have overestimated the velocity. This discrepancy could be due to a number of factors; the 2001 depths were based on the radargrams, not on time-slices which might cause some differences in how reflectors are interpreted and at what depth, secondly, we do not know what difference the change in antenna types and frequencies between the two surveys may have made, and finally, it is possible that the peat has shrunk or changed in character over the 5 years between the surveys.

9.4 Ground-truthing investigations

Given the unexpected results in the geophysical surveys, and the well established need for ground-truthing of reported detections of wooden structures in peat with GPR survey, the Canada Farm site of this case study was a priority for ground-truthing work. However, given the importance of both the ecology and archaeology, this had to be carefully negotiated with English Heritage, Natural England, Somerset County Council and the Department for Culture, Media and Sport. Eventually, a programme of coring was agreed upon, with provision for a small inspection trench to check the interpretation of the radar surveys.

The overall aim of the coring was to characterise the peat, in descriptive terms, over the grid, and to take a smaller selection of cores back to the laboratory for chemical analysis to look at the variation of key elements across the site, and over depth. This was to look for correlations between elemental concentrations and geophysical anomalies, to test the theory that the electrical and magnetic techniques were indirectly detecting the influence of the trackway on the local hydrology, causing minerals to concentrate or precipitate out of solution along its length.

Out of scope of this investigation were: examining any organic chemistry, palynology or other environmental reconstruction, speciating recovered elements, attempting to unravel the complexities on the anaerobic chemistry of the catotelm (for obvious reasons). The chemical analysis was not directed at explaining processes of enrichment or depletion, but was simply to looking for spatial variance in target elements known to influence conductivity and magnetic susceptibility to compare with the geophysical anomalies.

A small evaluation trench (1m x 2m maximum dimensions) was hand excavated to check for the presence (and depth) of any timbers, based on the GPR interpretation, and to recover a monolith through the first 1m of the peat. The monolith was the same depth as the recovered cores, and was collected to sample for chemical analysis, and to retain to offer to other environmental archaeologists to maximise the information from such a rare intervention opportunity.

The work was conducted on the 12-13 May, 2009. On the 12 May the evaluation trench was excavated, monoliths and wood samples taken (see below), and immediately backfilled under the supervision of Prof. T Darvill and Dr R Brunning (the senior Moors and Levels Archaeologist for SCC). The day was warm and dry, though the ground conditions were wet underfoot. The coring was carried out on the 13 May, which was wetter and colder, under the supervision of Dr M Allen.

9.4.1 Evaluation trench

On the 12 May 2009 a 1m x 2m evaluation trench was excavated in the region of GPR and other geophysical anomalies (see Figure 9.68). The trench was set out using dGPS, the location having been planned using rectified plots of the geophysical data.

Methods and observations

The trench was entirely hand excavated in a series of thin, arbitrary spits, each 5cm to 10cm deep, using trowels and shovels until the first signs of waterlogged wood were detected at 45cm below present ground surface. Excavation then proceeded to expose this woody level, and to take the rest of the trench down to the same level, using fingertips and plastic spatulas to avoid damage to the wood. Two sumps were also excavated to prevent flooding of the trench during this phase, and to ease bailing out as the excavation extended well below the local water-table.

None of the uncovered timbers showed obvious tool marks or evidence of human working, and largely appear to be birch roundwood, with bark remaining in the majority of cases. Some of the exposed and planned elements seem to be roots rather than timbers (Figure 9.69).

No diagnostic elements of the Sweet Track were found in terms of planks, horizontal timbers from the cross posts, or axe facets on any of the wood. The timbers were small, none presenting a larger a surface for GPR reflections than about 5-8cms in width, but did occur at about the depth of the most intense of the linear pattern of reflections identified in the survey. As noted above, this was about 30cms higher up in the peat than the recorded depth of the trackway in this sector at the time of the last excavations.

After consultation with the experts on site, the decision was taken to lift these pieces of wood and retain them for study at the university. This decision was not taken lightly as it was a potentially destructive one. The benefits were determined to outweigh the costs however;

- the timbers showed no diagnostic features that showed them to be structural elements of the Sweet Track, nor were they in close association with any other features or finds, thus limiting the 'damage' to any potential archaeological information to be gleaned from this small exposure
- There were some natural roots associated with them, which lends the possibility that this was natural deadfall preserved in the peat, rather than an

artefact of human activity; the trench was too small to adequately contextualise them in the absence of diagnostic elements or tool marks

- They were a little higher up in the profile than expected; therefore to adequately ground-truth the survey results, it was essential to excavate to at least the 'known' depth of the trackway, to ensure these were not simply lying on top of what we had actually detected in the surveys

This was a difficult decision. Once the timbers were lifted and placed in sealed bags with water from the trench, excavation proceeded to around 1m below ground surface, with no further sign of any woody material. This was at least 20cm deeper than the last recorded depth of the trackway, so we can now say with confidence that this timber seems to have been part of whatever was being detected in the GPR survey.

The excavation established that the timber lies at an interface between two types of peat, something that has been observed on other excavated sections of the trackway. It also showed the depth estimates of the anomalies in the GPR surveys to be accurate, that they were being caused by waterlogged wood, and allowed the recovery of a 94cm intact sample in the form of two overlapping 50cm monoliths.

It is now possible, therefore, to interpret these pieces of wood found during the evaluation as related to the Sweet Track; perhaps as off-cuts from its construction, but not as part of the track itself. R Brunning concurs that the parallel placement seemed like other outlying parts of the trackway that he had helped excavate during the SLP.

Post-excavation
The timbers and some samples of the peat collected during the excavation were wrapped in clingfilm with water from the peat and then sealed in plastic 'zip lock' type bags, and immediately refrigerated on return to the university, and remained in this sealed, cool environment below 5°C apart from when removed for testing or inspection.

Along with sections of the monolith, several of the wood samples were sent to Keele University for Relative Dielectric Permittivity testing by Dr Nigel Cassidy. The samples were sent by courier in an insulated cooled container and were refrigerated

upon receipt, and kept wet during the analysis procedure. The results of these tests are still awaited. A short paper is planned to communicate the results of these tests, and any implications they have for the interpretation of the GPR survey. Samples of peat from the monolith were sent with them, and it is hoped the tests will show if there are clear contrasts in RDP between the peat and the wood. If there are, the values obtained could be used in forward modelling to generate software models of different monuments and burial conditions and from these generate modelled GPR anomalies to help geophysicists interpret what is seen in field data. This process is commonly used in other environments to predict the responses of instruments to different targets.

Results

The evaluation trench located five pieces of timber, most arranged in a parallel linear configuration with each element following the same north-south orientation. These timbers lay at an interface in the peat, roughly 45cm below the ground surface, and were underlain by a horizontal root; suggesting they were deposited during a stable phase in the peat bog, one perhaps with some trees growing on the bog surface nearby, and then subsequently engulfed and preserved during a change in conditions in the Levels. No other features or finds were located in the trench.

Discussion

The evaluation trench confirms, as far as is possible without large scale excavations, that the GPR survey responded to buried remnants of prehistoric wooden structures, and that the depth estimates obtained seem to be appropriate. Several pieces of wood were uncovered that R. Brunning felt were likely to be part of the Sweet Track, even though no worked timbers were located. The orientation of the wood in the ground, its location at an interface between two peat layers, its association with the geophysical anomaly, and the known location of the Sweet Track mean we can assert that our GPR survey located the trackway. The elements located seem to perhaps be off-cuts or debris from the construction or renewal of the trackway, rather than diagnostic elements of the known structure of the trackway itself. It is worth noting that the Sweet Track had gaps in the structure where less material had survived, and that there were elements of a slightly older structure, the Post Track, running alongside or underneath it in places.

Furthermore, this confirmation that the trackway is in the position roughly indicated by the anomalies in all of the geophysical techniques means the coring investigations have a sound basis upon which to proceed; the geophysical anomalies do indeed correspond to the archaeology, rather than some hydrological feature of the peat. The presence of timbers at this depth also vindicates our interpretation of the depth of the trackway based on the GPR survey data, in contrast with the findings of the 2001 surveys (Utsi Electronics 2001).

Conclusion

The GPR survey directly detected waterlogged wood interpreted as being elements of the Sweet Track. The confirmation of the Sweet Track's presence in this location affirmed the assumptions that were behind the planning of the coring strategy; the logic of the coring programme was based upon the geophysical anomalies corresponding in some way, perhaps indirectly, to the presence of the trackway. The coring programme was of equal value in ground-truthing the geophysical surveys and perhaps even more important in terms of explaining the results from this particular site.

9.4.2 Coring and physical and chemical analyses

On the 12th of May 2009 under the supervision of Dr Mike Allen, a series of cores were taken in three transects across the geophysical survey grid, re-established using dGPS to the original survey location from 2007. Two transects ran west-east, one of which was a series of 10 gouge auger cores to record the sediment characteristics at 2m intervals where possible, and one was slightly wider spaced, with irregular intervals, of Russian sampler cores. There were four cores taken, over a depth of 1m. A further two cores were taken at the mid line of the north and south sides of the survey grid, giving a three core transect perpendicular to the first; see Figure 9.68 for the core locations.

This coring layout was planned, and modified in the field to adapt to local conditions, to give reasonable spatial coverage across the main axis of observed changes in the geophysical surveys; west to east, with some additional information working north-south. 1m of peat was recovered from each of the Russian core samples, taking two 'bites' with a 0.5m corer in two separate holes, given the problems of compression and loss at the tip associated with this instrument. The gouge auger transect was

conducted to the first contact with the Somerset 'blue clay' layer that is very distinctive and underlies the peat in this area. Major interfaces and sedimentary units were recorded by description and using a Munsell colour chart. There were some problems with the gouge auger voiding when particularly wet and well humified deposits were encountered but the depth of this zone seems to have been fairly consistent across the site, and so it does not seem to have unduly introduced major inaccuracies in the profiles recorded.

Method

Once the Russian sampler cores were removed from the corer they were immediately wrapped in clingfilm and then rested in a length of drainpipe to support them. On return to the University that day they were immediately frozen at temperatures kept below -24°C. They were stored flat at all times. On 11 June 2009 they were sub-sampled into 10cm sections for all further tests. They were slightly defrosted and cut up while still mostly frozen to try to limit the movement of water within the core. These sub-samples were then placed in individually labelled zip lock type bags and kept sealed and refrigerated at or below 5°C. The aims of these storage and processing methods were to keep the cores and sections cool to limit microbial activity and, as far as possible, to limit oxidation reactions.

A series of tests were the used to determine some of the physical properties of the samples, as well as the digestion of the samples for Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) analysis to determine the elemental composition of the peat and pore water. The methods and results of each of these tests will be discussed separately below, and then the overall implications of these results for the interpretation of the geophysical surveys will be discussed in a combined conclusion.

Water content and LOI tests

Water content and Loss On Ignition (LOI) testing were combined with the collection of pore water for analysis in the ICP due to the limited quantities of material available for testing. These were also by necessity single sample tests, for the same reason.

As such, the moisture content tests followed a slightly modified procedure than that outlined in Avery & Bascomb (1982), which was used as the manual for all of the other physical property tests conducted in this research. Around half of the 10cm sub-sample was taken for each sub-section of the core, and weighed. It was then compressed by hand (using nitrile gloves to minimize contamination) and the pore water collected and retained (refrigerated at or below 5°C) for further testing. The remaining sediment was weighed. The percentage of weight lost in this step was calculated, and then this squeezed sample was further sub-sampled for LOI testing. The sub-samples were again weighed, then dried at 105°C for at least 24 hours to remove any remaining free and interstitial water, and weighed again. The further percentage of weight lost was then calculated and combined with the amount from the first step to give an approximate calculation of moisture content.

The air dried samples, of known weight, were then ashed in a baffle furnace at 450°C for at least 12 hours and then re-weighed. The weight lost was calculated, giving the loss on ignition, which represents the organic material present in the original sample.

Results

The results in are displayed as Figures 9.70 and 9.71.

These tests were also carried out on the monolith samples, again sub-sampled to in 10cm spits, though the pore water was not collected so the moisture content calculations are more accurate. The results are summarised in Figure 9.72.

All of the samples, apart from one (see below) were technically 'peat'; i.e. they had more than 40% organic material by weight. Patterns were observed in how organic the sediments were; generally, the cores follow a pattern of having more minerals present in the active layer (the first 20-40cm), with this falling off with depth. Generally speaking, the maximum mineral content is about 20% at the surface, dropping to 5% in the first 40cm or so. In the monolith and in Core 4 this pattern was not followed. In Core 4 there is a large jump in the mineral percentage in the 60-70cm sample, up to 95% of the sample, rather than the inverse. The rest of the core follows a more typical pattern. The monolith does not show the expected increase in mineral content at the surface; the overall mineral content is reduced by about 5% for the whole monolith,

apart from the 80-90cm sample (the deepest that enough material could be recovered from for this test), where it jumps to about 30%.

The moisture contents do not vary much; they are very high overall with most values falling between 90-95% of field-wet weight. Two sequences of samples were exceptions to this, Core 6, which came from the southern side of the grid, and the monolith. Core 6 was noticeably drier when it was taken in the field, and was from an area of the site closer to a drainage ditch lined by trees where the vegetation cover had started to change to reflect this. Values obtained for this Core ranged from around 80-90% moisture. The monolith showed strong changes with depth, but it is possible that some of these differences were caused by water moving through the peat column during storage, as the monoliths were not frozen prior to being sub-sampled. The monolith showed about 80% moisture content for most of the samples, with the deepest bulk sample (80-90cm) possible showing much more, around 95%.

Analysis of elemental composition
As stated above, the primary aim of taking the Russian sampler cores was to conduct chemical analysis of the peat and pore water to investigate the possibility that chemical differences in the composition of the peat were giving rise to the geophysical anomalies, rather than the trackway directly. The working hypothesis was that the trackway was forming a hydrological barrier or conduit and causing different minerals to precipitate out of solution at different depths, or in greater or reduced concentration compared to elsewhere on the site.

This hypothesis was formed after consideration of evidence from Star Carr (Boreham *et al.* 2009) which seemed to show differential precipitation of iron sulphides due to fluctuations in the seasonal water-table. There is also evidence from peri-marine peats that saline waterlogging causes the leaching and redeposition of iron in quantities large enough to register as magnetometer anomalies (Kattenberg & Aalbersberg 2004). While this process is not assumed to be operating in the Somerset Levels, it is possible that the area was subjected to marine inundations in the past, and it was also hypothesised that there might be pockets of brackish ground water that were contributing to the conductivity gradient apparent in both the resistivity and EM surveys. It is also possible that deposition of iron oxides might cause GPR reflections,

or, that if the timbers had become mineralised that they could have enough iron present in them to cause the same effects (Van Dam *et al.* 2002).

With this in mind, the coring strategy was developed to allow a picture of possible changes in composition over the grid, mainly in the direction perpendicular to the trackway and associated geophysical anomalies, but also with a less detailed transect parallel to the line of the trackway.

Given the high water content noted above, and the very high organic contents to be expected in peat, it was decided to digest wet samples of the material rather than dried ones, in case chemical changes happened during the drying process, and some of the more volatile compounds might have been lost as gasses during the drying process (for examples, sulphurs held as iron sulphides in the wet peat).

The 10cm sub-samples of the cores were further sub-sampled into three repeats of each 10cm section for digestion and analysis by ICP OES along with nine samples of a Certified Reference Material (CRM), TH-2. This is a sediment rather than a soil, and was selected because this CRM has a large number of certified metals, and is also from a waterlogged context (though supplied as a dry sample of the <63mµ fraction). The CRM material was digested dried, and also in two levels of dilution in deionised water, to check for effects introduced by the presence of the pore water in the peat samples diluting the acids used for digestion.

Digestion method
Standard aqua regia methods, usually used for the analysis of available metals and other elements, in soils and sediments can underestimate the quantities of iron present. As this was one of the primary elements of interest, a modified warm nitric acid digest was followed to try to overcome this issue. CRM materials were digested to allow checks on the efficiency of the digest procedure. Given the largely organic and water based composition of the sediments, it can be assumed that the recovery rates are much better than for the CRM materials, as very little solid material was observed to remain following the digestion and re-suspension. This modified digest was developed at Bournemouth University for the analysis of plant materials and sewerage

sludge by Dr M Smith. It uses nitric acid alone, rather than adding sulphuric acid, as follows:

1. Digest 2.5-3g of wet sample in weighed test tubes, then re-weigh. Add 15ml of 70% HNO_3. Agitate frequently to start with and place in heating blocks. Agitate while heating blocks come up to 40°C
2. Leave at 40°C for at least 100 hours, checking and agitating to remove any plugs of organic material that may rise up the test tube
3. re-agitate and turn blocks up to 60°C for 3 hours checking after 2 for plugs
4. turn up to 105°C for at least 12 hours
5. Agitate and bring up to 130°C and leave until dry, removing dry tubes as they dry to avoid scorching the residues, can take up to 24 hours
6. re-wet with 5ml of 75% HNO_3 and bring up to 105°C for one hour then turn blocks up all the way until evaporated, as in previous step
7. Re-weigh and record dried tubes once cooled
8. Add 5ml HNO_3 and warm at 80°C for 30 minutes
9. Add 20ml de- ionised certified water and warm at 60°C for 20 minutes and cool to room temperature
10. Re-weigh (aiming for 25.525g less dry sample + tube weight)
11. Filter into 30ml sterile plastic re-sealable tubes through Q2-10 papers (using acid washed funnels) and refrigerate until needed for analysis

Nitric-only digests have been used in archaeological multi-element studies on peat soil samples from settlement sites with good results (Wilson *et al.* 2008).

In all, 219 samples were digested by this method, and presented to the ICP OES for analysis. Two standards were used to calibrate the machine during the analysis, giving a suite of 30 elements, with several emission spectra for each element.

The output from the ICP OES was combined with the data about sample weights and dilution factors from the digest process, in MS Excel and the dilution factor applied to the ppm outputs from the ICP OES to give ppm in the original sediment, or milligrams per kilogram, which is the standard unit for discussions of trace elements in sediments.

The resulting data was exported into SPSS (SPSS Incorporated 2006) and, using the three repeats of each core section, an average ppm was calculated, along with the standard deviation, for each spectral emission line. These were then re-imported to MS Excel. The following discussions are based on those averages, from selected emission lines. The emission line was selected based upon two factors; firstly, due to the nature of ICP analysis some of the emission lines failed to calibrate for part of the analysis (the instrument was set to recalibrate against the standards every ten samples). Secondly, the emission spectra differed in their variability; some had generally better (i.e. smaller) standard deviations; so in each element of interest the emission line with the lowest standard deviations, where there were calibrated measurements for all 219 samples, was selected to look at in detail. There is a vast amount of information in the research archive that has not been looked at in detail as it is not directly relevant to the questions at hand, but that is preserved and available to future researchers. The collected pore water was also directly analysed after being centrifuged to reduce particulates to avoid damage to the ICP OES equipment. The resulting ppm data is included in the project archive but concentrations were too low and highly variable to include in the discussion. It is also possible that significant migration of pore water occurred in the sample prior to it's collection.

Results

First of all it is important to consider the results obtained from the digested CRM materials to establish the minimum recovery rates of the digestion method.

Figure 9.73 shows the expected vs. the values determined by our method, for the dry CRM samples. The reference values were obtained using the aqua regia method, which closely follows the method outlined above, but with the addition of hydrochloric acid. Recovery rates were shown to be acceptable for the elements of interest, and it can be assumed that for the peat samples, the recovery rates were higher as there was very little undigested material remaining on the filter papers at the end of the process, meaning most of the metals and other elements had passed into solution in the HNO_3. Some elements (particularly tin, Sn) appear to be being overestimated, but this could be contamination or experimental problem, or it could result from how the dilution factor was calculated. These experiments were not

looking at absolute concentrations of the elements; they focus instead on relative changes in concentrations present over depth and across the survey area, so potential systematic errors in the ppm estimations do not affect the interpretation.

What follows is a description of the results for each element considered in detail, preceded by the reasoning for considering that particular element. The potential geophysical implications for any variations are reserved for the *discussion* section, below.

Iron

Iron minerals, especially iron oxides such as magnetite and hematite, are very important in the human enhancement of the magnetic properties of soils. These processes are inhibited in waterlogged contexts (Thompson & Oldfield 1986; Weston 2004), though it has been demonstrated (Kattenberg & Aalbersberg 2004) that this process is complex, at least in saline environments, with the iron being redeposited elsewhere in the sediments in concentrations strong enough to cause magnetometer anomalies. Work at Star Carr (Boreham *et al.* 2009) has used ICP analysis of the peats to identify 'vulnerable' sediments which have a greater propensity to become more acid or reach a higher cation exchange capacity on exposure to air. This process is dependant on iron sulphides, and seems to be related to the presence of a seasonal water-table with different species of iron precipitating from solution into the sediments at the maximum and minimum extents. Iron oxides have also been demonstrated to cause GPR reflections, as mentioned above, so iron is an element of great interest as a possible explanation of the geophysical surveys.

Selected line: 239.563nm; see Figures 9.74-9.75

Generally speaking, in most of the cores, the iron has a small concentration at the surface and then a reduction, followed by an increase lower down, from around 0.7m downwards.

Looking at the average concentration (worked out by averaging the ppm counts for each of the core sections), there is a variation both moving west-east across the grid, with an increasing trend that is at its maximum in the samples obtained from the

monolith, and reducing slightly to the east of them. There is a decrease from south to north. When examined in conjunction with a visualisation of the maximum and minimum concentrations observed in the core, there is a strong pattern of change in the samples from the monolith, at 16m across the transect, with the general pattern of the minimum overlying the maximum being reversed. In the south-north series, the depth of the maximum concentration increases as the average concentration also falls off.

Sodium

Salinity is directly related to soil conductivity; in fact, when researching laboratory methods for determining the salt content of a soil, all rely on electrical measurements of the conductivity of soil pastes in the lab, or the use of EM techniques in the field. Since we were seeking to explain an electrical change by the presence of mineral salts, it would have been tautological to use these tests, so instead, sodium was one of the elements quantified in the analysis. Sodium is, however, a hard element to avoid in the laboratory and general environment, and so any results need to bear in mind potential contamination during the digestion and sample preparation process.

Anecdotal evidence from the tenant farmer at the Old Peat Works site suggested that there might be pockets of saline ground water from previous marine inundations, as during a conversation he indicated that boreholes for water for livestock in the area had proved to be brackish.

Selected emission line: 568.821nm; see Figures 9.76 to 9.77.

These distributions are noisier, with greater standard deviations that may be masking underlying patterns. Generally speaking, there is a slight peak in concentration at or just under the surface, and then the situation is more complex; some cores (1, 5 and 6) show a peak in the 50-60cm region, but the others do not. Overall, there does seem to be some variation with depth, with a slight increase in the lower part of the profile, apart from the monolith which shows a gradual increase from the surface to about 70cm then a sudden drop for the last 30cm of the core. The 'noisiness' is much reduced in the monolith data as well.

When looking at the average concentration from west to east, there is a generally decreasing trend, with the monolith samples creating a small peak against the trend. From south to north there is also a decrease in concentration. The maxima and minima in the west-east transect follow the same pattern, with both being deepest in Core 1, and rising to their highest in Core 2. The minima then drop off slightly and level out, while the maxima drops markedly in the monolith, down to around 70cm deep, then increases again in Core 3. In the south-north transect, the height of both the maxima and minima increase as the concentration decreases, the maximum from 70cm deep to 10cm deep over the transect, and the minimum from 90cm to 60cm deep.

Sulphur

Sulphur is of interest in part due to its association with iron in waterlogged deposits, and for its more complex relationship with the behaviour of water in the catotelm (Clymo 1983). As the elements could not be speciated, it was not possible to make the distinction between sulphides and other forms of this element.

Selected emission line: 181.972nm, see Figures 9.78 to 9.79.

The cores generally show a very slight increase in concentration at or near the surface, then a dip, followed by a strong increase in concentration with depth. The data gets noisier with depth as well, with a marked increase in standard deviations. The monolith samples were outside this pattern, with a peak at the surface and at 60-70cm deep, with relatively low amounts detected in the last 30cm of the core.

The west- east transect shows little change, as do the maxima and minima, occurring between 80-100cm deep and 0-30cm deep respectively, apart from in the monolith where this pattern reverses and the maximum lies in the 60-70m deep sample, and the minimum below it in the 90-100 deep sample.

There is a decrease in the average amount from south to north, but the minima are all in the 20-30cm sample, though the maximum raises from the 90-100cm deep sample in Cores 5 and 4 to 60-70cm deep in Core 6.

Manganese

Manganese shares many properties with Iron, for example, it forms different species between the acrotelm and catotelm (Clymo 1983, 182), in part due to forming sulphides in the catotelm, whereupon it becomes less mobile. It is of interest therefore to map concentrations of this element, even though the ICP technique used cannot speciate it, to look for areas of concentration and depletion to help define both the acro/catotelm boundary and to shed light on the hydrology.

Selected emission line: 260.568nm; see Figures 9.80 to 9.81.

Manganese is generally less abundant, but follows a similar pattern to the iron in terms of distribution over depth; there is a strong peak in the top 10cms, then a dip, followed by a gradual increase to a maximum somewhere in the last 30-40cms of the Core with the values remaining elevated around the maximum. The monolith follows this pattern, but shows a much lower peak at the surface, despite having a higher average concentration.

The west-east transect shows quite strong variations, but these are exaggerated by the low average concentrations of this element. The values are high in Core 1, reduced in Cores 2 and 4, then high again in the monolith and Core 3. The maxima and minima are less varied; generally the maximum concentration is within the top 10cm, and the minimum occurs somewhere between 20 and 40cms deep, apart from in the monolith, where the lack of a surface peak means the maximum occurs in the 70-80cm range, and the minimum in the 40-50cm range.

The south-north transect shows very little change, in comparison, either in the average concentration or in the depth of the maximum and minimum concentrations.

Phosphorus

Phosphorus is an important chemical in archaeological soil science; relative increases have been shown to locate settlement sites (Craddock *et al.* 1985). It is associated with human and livestock effluent in particular, and so can be seen as an indicator of settlement or animal husbandry. It is also known to be released from peat when it is

frozen and then thawed (Clymo 1983, 182), so the results from the cores may have been enhanced by this process.

Selected emission line: 213.618nm; see Figures 9.82 to 9.83.

The cores show a very high peak at the surface, with the exception of the monolith samples, then generally consistent concentrations, with a small increase somewhere in the 40-70cm region. The monolith shows this increase as well, but then a further slight increase over the last 30cm of the core.

The west-east transect shows a higher value in at the western edge, a drop for Core 2, and then a rise with the monolith sample forming a peak, but then dropping back slightly in Core 3. The maxima and minima generally run at the surface and between 30-40cm respectively, but with the minimum much deeper in Core 1, in the 90-100cm section, and in the monolith where their relative position reverses, with the maximum at 80-90cm and the minimum at 40-50cm.

The south-north transect shows a decline in the average concentration, dropping steeply between Core 6 and Core 4, and only slightly to Core 5. The maxima are all in the first 10cm of the core, but the minimum is at 80-90cm in Core 6 and at 20-30cm in Cores 4 and 5.

Magnesium

Magnesium has been considered in a number of studies of peat inorganic chemistry, and has shown mixed distributions but when the Calcium: Magnesium ratio has been examined it can be used as a proxy indicator for the limit of influence of any adjacent, underlying or overlying mineral soils (Clymo 1983, 185).

Selected emission line: 279.800nm; see Figures 9.83 to 9.84.

The cores show a trend towards increasing concentrations with depth, with a peak in some between 50 and 70cm, with a slight reduction below this. The monolith samples broadly conform, though with a slight decrease over the first 50cm of the core and a larger increase in the 50-70cm range.

Over the west-east transect, the average values follow a similar pattern to those of the phosphorus and manganese, with a slight elevation in Core 1, then a dip, reaching their maximum in the monolith before reducing again slightly in Core 3. The maximum concentrations in this transect start near the base of the core, but rise along the transect to 50-60cm in Core 3. The minimum is at or near the surface for all of the cores apart from the monolith, where it lies at 40-50cm.

The south-north transect shows higher average values in the centre of the grid, Core 4, but with a corresponding raising of the minimum concentration, and a lowering of the maximum.

Potassium

Potassium has also been examined in previous studies, and has been demonstrated to peak at the surface before falling off rapidly (Clymo 1983, 185). It was therefore a useful element to examine to see how well these profiles corresponded to the expected distributions.

Selected emission line: 769.897nm; see Figures 9.85 to 9.86.

The cores show a strong surface and near-surface concentration of this element, with a dramatic reduction after the first 30cm of the core, though there is a very slight elevation in values around 40-60cm. The monolith shows an almost totally reversed distribution, with very small values recorded for most of the sample, then values greater than recorded in any of the cores present in the 70-100cm sections.

This has an impact on the average values in the west-east transect, with a double peaked distribution, with Core 2 and the monolith being the peaks. The maximums are, as stated, all in the first 10cm section apart from the monolith, where it is in the 70-80cm section. The minimums vary, but they lie in the 60-90cm range, apart from the monolith where it is at the 30-40cm section.

In the south-north transect, Core 5 shows an elevated average concentration in comparison with the other values obtained, but the maximums and minimums do not vary, lying in the 0-10cm section and the 60-80cm range respectively.

Calcium

As stated above, the calcium to magnesium ratio has been used to suggest the limits of influence of any mineral soils on the peat and ground water chemistry of a given mire ecosystem. Calcium is also likely to have an effect on the pH of the peat, influencing the trophic status of the mire. Like iron and to a lesser extent, magnesium it is also generally expected to show a peak in concentration at the surface of the system, and in the basal peats, but be depleted in the middle peat.

Selected emission line: 317.933nm; see Figures 9.87 to 9.88.

This element proved to be particularly noisy, as can be seen from the standard deviations on the charts. Patterns are therefore, harder to observe, but there seems to be a trend towards an increase in values over depth, quite sharply after the first 30cm or so of the core, and peaking at around 50-70cm and either tailing off or remaining elevated. The values from the monolith samples showed generally higher values and a slightly different pattern where the concentration rises less sharply to a peak between 50-70cm, then a stronger reduction in the last 30cm of the core.

This has an effect on the west-east transect, with a peak forming in the average concentration with the monolith. The maxima and minima generally lie between 50-90cms and 0-20cms respectively, apart from in the monolith where they are at 50-60 and 90-100 respectively.

The south-north transect is more simple, with a large drop in the average concentration at the north edge of the grid in Core 5. The maxima and minima vary little, lying between 60-90cm and 0-20cm respectively.

Copper

Like iron and manganese, copper forms sulphides in the catotelm (Clymo 1983, 182), and is therefore of interest in terms of zones of concentration and depletion in understanding the behaviour of water within the peat matrix.

Selected emission line: 324.754nm; see Figures 9.89 to 9.90.

The cores show very low concentrations of this metal, but with a large increase at the surface, dropping very rapidly over the first 20cm of the core. There seems to be a slight increase observed in the 50-60cm section. The monolith shows slightly elevated values in a very different pattern, with suppressed values in the majority of the core, but elevated values in the 70-100cm sections.

The west-east transect shows an increase in average concentration that corresponds to the monolith, but is otherwise relatively stable across the transect. The maximum concentrations are all observed in the first 10cm of the core, apart from in the monolith where this occurs in the 80-90cm section. The minimums all lie in the 20-50cm range.

The south-north transect shows less variation, with a slight decrease in average values over the transect. The maximums are all at the surface, in the first 10cm of the cores, and the minimums all lie between 20-40cm.

Tin

Measurements of this metal were taken to compare and contrast with the others and to look for obvious zones of depletion and concentration, and to see if any of the cores did not fit any patterns established.

Selected emission line: 242.950nm; see Figures 9.91 to 9.92.

The cores show generally low concentration values for this element, but with an observable increase in the last 40-30cm. The monolith shows slightly elevated values, but follows a similar pattern.

The west-east transect shows an increasing trend in the average value from west to east, that peaks over the monolith. The maximums all lie within 60-90cm and the minimums between 10-40cm apart from the monolith, which lies at 40-50cm.

The south-north transect shows a slight decrease in the average concentrations from south to north, with the minimums all in the 10-20cm sections, and the maximums lying between 60-90cm.

Nickel

Measurements of this metal were taken to compare and contrast with the others and to look for obvious zones of depletion and concentration, and to see if any of the cores did not fit any patterns established.

Selected emission line: 216.555nm; see Figures 9.93 to 9.94.

The cores show low overall concentrations of this element, but with a noticeable relative increase at the surface, and in all cores a peak, and in some cases a strong one, between 50-70cm, with a fall off over the rest of the core. The monolith shows similar values, and a surface increase, but the peak in values occurs lower, between 80-100cm.

The west-east transect shows some variation, but this is probably more due to the very low values and the noisy response. The maximums and minimums vary across the transect with the maximums varying from 0-10cm in Core 4 to 80-90 in the monolith, and the minimums from 20-30cm in Core 4 to 50-60cm in the monolith.

The south-north transect had more clear trends with an apparent reduction in average concentration (though with the small values, it is harder to argue for a 'trend' as opposed to random variation). The maximums all occur in the 0-10cm samples, and the minimums between 20-50cm.

Aluminium

Measurements of this metal were taken to compare and contrast with the others and to look for obvious zones of depletion and concentration, and to see if any of the Cores did not fit any patterns established. Previous studies indicate that it shows high

surface concentrations before falling off rapidly with depth (Clymo 1983, 185). Aluminium becomes highly mobile if the pH of the sediment falls below about 5.5, so its distribution was also considered in this light.

Selected emission line: 237.312nm; see Figures 9.95 to 9.96.

The cores show a strong relative increase in the first 10cm sample, and then a smaller peak in the 60-70cm section, and a very slight increase in the 90-100cm section. The monolith is quite different, with higher maximum values, and with these occurring in the last 30cm of the core and being suppressed elsewhere.

The west-east transect shows a strong spike in average concentration associated with the monolith, which is superimposed on a trend of lowering values from west to east. The maximums are all in the first 10cm of the core apart from in the monolith where it lies at 70-80cm. The minimum shows an upwards trend from west to east, in Cores 1, 2 and 4, rising from 80-90cm to 20-30cm. It is at 20-30cm in the monolith and then drops to 80-90 again in Core 3.

The south-north transect is more simple, dropping to a low in average concentration in Core 4, before rising slightly in Core 5. The maximums all lie at 0-10cm, and the minimums between 20-40cm apart from Core 5, where it drops to 80-90cm deep.

The concentrations over depth for each of the studied elements in the monolith are shown in figure 9.97 and 9.98.

Magnetic susceptibility tests
Magnetic susceptibility measurements were taken on all of the core samples, sub-samples of the monoliths, and of the underlying blue clay deposit to look for magnetic contrasts on the site that might help explain the gradiometer response to the trackway. Measurements were made using the Bartington MS2 system, using the MS2B dual frequency laboratory sensor.

The instrument was initially calibrated using a certified sample, then 3 measurements were taken for each sample, using both the low and high frequency modes, and an

average calculated for each frequency. This average was then converted to mass specific measurements using the weight of the sample. The low and high frequency results were then compared to calculate the % frequency dependence, allowing an estimation of whether the magnetic susceptibility is being produced by large or small particles, as the response for a given frequency varies with the grain size of the ferromagnetic particles producing the effect. This followed the methods and calculations set out by Dearing (1999).

Where possible, each 10cm sub-sample was measured but where there was not enough of the sample (as the technique relies on being able to homogenously fill a 10cc pot), it was combined with the next sample. For example, in Core 4 there was not enough of the 0-10cm sample, so a sample was made up that was half from 0-10cm and half from 10-20cm.

The results are displayed in Figure 9.99. The values for the monolith are shown in Figure 9.72. In these displays the mid-point of the depth range of each sample has been used as the depth value to plot the trends.

The values obtained were generally very low and with this in mind, it is perhaps presumptive to talk about patterns, given that much of the variation shown in the results is close to the threshold of variations caused by instrument noise and experimental conditions, though efforts were made to minimise these.

We can generally state that the observed values are low, and even negative, indicating possible diamagnetic properties in the sediments, perhaps caused by the extreme waterlogging; many of these samples are more than 90% water. Generally speaking, the values also seem to reduce with depth, with an exception for the low frequency response in Core 2. There is also no great spatial variation in terms of the values seen in different cores, apart from in the monolith, when values were lower, being negative in all of the low frequency measurements and half of the high frequency ones.

Though measurements were taken at both frequencies, and the results presented, the values recorded were too low for any meaningful observations about frequency dependence to be made (Dearing 1999).

Discussion

This discussion deals with the laboratory tests, including the ICP elemental analysis as a synthesis as the properties of the peat investigated interact in both complex and simple ways. In some cases, the relationship is relatively straightforward. For example, moisture content is causally linked to the organic matter present, in a positive feedback loop. The magnetic susceptibility of a soil is also influenced by both the water content and organic matter present, but as part of a complex set of variables that also includes the relative compaction and the presence of iron (and other ferri- or ferromagnetic minerals) amongst others.

With this in mind, it is also important to reiterate that this investigation intended only to look for patterns in the distribution of elements, or changes in the physical properties of the peat that relate to these complex causal relationships. It was not intended to prove, or disprove any of the causal links for this particular site, or to establish the mechanisms whereby such differences, if they existed, arose. That is a question further research will need to focus on. However we can make reasonable suggestions about these relationships based on our observations of the data.

What was immediately clear from the geophysical results was that there were differences in the properties of the peat that influence the particular techniques employed. This, as had been stated, was more than a little unexpected. The inherited assumption was that this type of peatland environment would be too wet for there to be observable or meaningful contrasts in the resistivity data, that the same waterlogging would have inhibited soil magnetism to the extent that the gradiometer and MS surveys would be useless, and that there was only a slim chance that there would be sufficient contrast between the peat and the trackway timbers for the GPR to detect a reflection.

Besides the linear anomaly in the location of the Sweet Track, there was also a conductivity gradient running across the area surveyed in both the EM and twin probe resistance surveys. This gradient is what suggested that we might need to turn to chemistry to explain why we were detecting anomalies in this environment. It also suggested that there might be some sort of lateral flow through the site, perpendicular

to the trackway, and that effects from this were what we detected in most of the surveys, rather than the track itself.

When dealing with resistivity, archaeologists work with the inherent assumption that the anomalies they are dealing with are caused by contrasting moisture levels in the soil, caused by changes in the physical composition and structure of the soil by past human activity. On most sites, this is a totally valid assumption to make, but soil structure and composition is not the only influence on conductivity;

> *The ability of the earth to conduct the current will depend on the concentration of ions within the ground water, the total moisture content of the earth and the geometric arrangement of the moisture holding pores within it.*

(Carr 1982, 9)

In his exhaustive investigation of the factors that influence the resistivity of anthropogenically influenced soils, Carr (1982, 49) shows that at higher resistances the chemical make up of the pore water overtakes soil moisture and structure as the driver of changes; for example detecting saline groundwater plumes in rocky aquifers. At the lower resistances expected for archaeological sediments, the moisture/structure aspect is more important. We would propose here, that in conditions of very low resistivity, and where soil moisture content and structure are largely homogenous, at least in slices (i.e. the different layers of peat over depth), chemistry starts to show an influence as the other, usually 'louder' variables are not in effect.

However, the chemical factors that influence soil conductivity are highly complex, with lots of interconnecting relationships. They also have an effect on the physical makeup of soils in that the Ca:Na and Mg:Na ratios in turn encourage or discourage colloidal flocculation in both clays and organic matter, which in turn affect how much water the soil can hold (Carr 1982, 77-78). Carr gives us four 'operational variables' which explain the conductivity of soil pore water if we conceptualise it as an aqueous solution; ' *a) the kinds of ions present in the water, b) their concentration within the water, c) the concentration of conductive colloidal particles, and d) the temperature*

of the water' (1982, 79). He further qualifies this, stating that pure water has poor electrical conductivity, but the conductivity increases if you add ions, colloids and heat, but that the relationships between these factors are complex and not entirely understood. Therefore, they are beyond the scope of this investigation.

As can be see, one of these drivers was constant for the course of our investigation, at least in the horizontal plain; temperature, so the variations in our electrical dataset are likely to being produced by the other two factors (as we have already established that moisture content was relatively homogenous, at least in horizontal space; it visibly varied with depth). As has been stated, the equipment available did not allow the differentiation of species of elements present. We were not able to look at the ions of an element present, or determine what substances they were combining to form, but we were able to look at total elemental concentrations as a proxy measure. Sodium (Na) has already been mentioned as an important element in determining soil structure/soil moisture, but it is also a key element in the chemical variation of conductivity as well. It forms salts with other minerals and combines with them to form electrolytes which make the pore fluid more conductive (by increasing the concentration of ions, as well as creating conductive colloids). The average sodium concentration (see above, and Figure 9.77) co-varies with the conductivity; it drops as the transect of cores moves W-E across the grid, matching the gradient in the geophysical data. It also 'spikes' in the monolith; creating or strengthening the low resistance/high conductivity detected there. Inversely, Magnesium (Mg) counts rise, generally speaking from W-E along the main transect, and the depth of their maximum expression comes closer to the surface. As previously stated, this change in the Mg:Na ratio discourages flocculation in clays and organic particles, contributing to higher resistances. The calcium (Ca) counts were very noisy and do not seem to relate to the conductivity in a simple manner. The other elements examined include a number of metals, because of their potential to form mineral salts. They were generally found in very low concentrations, or, in the case of aluminium (Al) and iron (Fe), to have quite complex patterns with large surface concentrations. It is harder to directly relate these elements to conductivity changes, but there are distinct variations, described in detail above, in the monolith samples, in contrast to the general distribution patterns in the other cores.

Soil magnetism is also affected by both chemical composition and physical factors. Ultimately, the magnetic response is controlled by the number of magnetically susceptible particles, whether they are thermoremnantly magnetised, or created by the heating and cooling of ferrous oxides within the soils' mineral components. This is a function of both the original chemistry of the soil, and the processes it has been subjected to, including the addition of material such as ash, waste products, pottery and food waste, as well as in-situ heating or burning. This is further affected by the compaction of the soil; how many of those magnetised or magnetisable particles are packed into a given spatial unit of the soil that being surveyed (Thompson & Oldfield 1986; Clark 1996; Dalan & Banerjee 1998a; Dearing 1999; Marmet *et al.* 1999; Gaffney & Gater 2003). Given that these soils were saturated, and not considered to be from a settlement, or otherwise anthropogenically influenced, the usual expectations of higher soil magnetism (as measured by magnetic susceptibility) in the topsoil and in the fills of features like pits and ditches did not apply.

As expected, the geophysical surveys were very quiet, with very low MS measurements both in the laboratory and in the field, and very little disturbance in the gradient of the Earth's magnetic field. There were anomalies in the gradiometer data and in a wet generally homogenous environment; differences in the amount of iron oxides present seem a reasonable explanation. As speciation of the iron was impossible, its overall distribution and covariance with sulphur and manganese was examined in the ICP data. All three of these elements form a similar pattern, with a slight peak in values at the surface, a drop off, and then an increase in the lower 40-30cm of the core, and they all vary from this pattern in the monolith. The monolith samples, as with other elements, show a slight increase in the average concentration. However, the maximum expression of iron was higher up in the profile than elsewhere, and the minimum towards the base.

Without being able to speciate the iron, explanations for this apparent paradoxical effect are hard to reach, but two things should be considered. Firstly, the anomaly noted in the gradiometer survey was displaced by 1-2m west compared to the other linear anomalies observed. This places the gradiometer anomaly somewhere between core 4 and the monolith- it is possible the dip in iron concentrations shown in core 4 in contrast to the monolith are producing the anomaly. Secondly, in the magnetic

susceptibility tests, the cores all proved relatively similar, with a pattern of very low values (from just below zero up to about 5 SI), which tended to fall over depth. The values for samples from the monolith showed much lower values, between 2 and -3 SI, and very little change with depth, despite the increased Fe concentrations, suggesting that some or all of the iron in the monoliths was in less magnetic forms.

These very low MS values were expected, given the waterlogging and the lack of any settlement activity in the vicinity. The differences in the response of the monolith samples, along with the apparently increased and altered distribution of Fe and related elements were anticipated from the geophysical surveys, but future research is needed to examine exactly what the causal processes are here.

An examination of the moisture content and LOI data (Figures 9.70 to 9.72) illustrates neatly why this is the case; these samples are very wet, and very organic, though the differences in the monolith samples do not adequately account for the differences in MS observed; as stated, this needs to be the focus of future research.

The gouge cores were logged in the field and the sediments characterised and described; this has allowed major interfaces to be plotted as Figure 9.100. When this diagram is examined, one thing stands out; in almost all of the cores there was a void where the material was too wet and poorly structured to be recovered by the gouge method. This typically lies at or around 1m deep, and appeared to be a continuation of the wet and woody peat layer that generally started at about 70cm down; this is where a lot of the secondary peaks in elements were noted, suggesting that this is the top of the permanent water-table with some elements precipitating out of solution here, as suggested by Boreham *et al* following analysis of the peat from Star Carr (2009).

9.5 Conclusions

At the Canada Farm site, all of the geophysical survey techniques employed detected anomalies associated either directly or indirectly with the Sweet Track. Ground-truthing investigations have confirmed that, apart from in the GPR survey, these anomalies appear to result from the chemistry and hydrology of the peat, rather than the specific characteristics of the preserved wood, which is what appears to be producing the GPR responses.

Overall, it is possible to say that there are variations in the distributions of key elements that appear to match the variation in the geophysical results, particularly the conductivity gradient, the low resistance anomaly associated with the Sweet Track, and the negative gradiometer anomaly offset from the trackway. There are two explanations for this, and it is likely that both are relevant here.

The first interpretation of these results is that there are large differences in how elements (especially metals and mineral salts) are distributed in the area immediately around the trackway, probably caused by the trackway disturbing the normal throughflow of water in the peat, as shown by the LOI tests. These concentrations are such that geophysical responses are produced; this effect might not be noticeable on a dry land site as they are very small scale responses, only visible due to the low noise in these surveys. As the physical and chemical processes in peat are still being explored, attempting more of a causal explanation than this is beyond the scope of the present research project, but there are important questions here for further research.

A second explanation for the large differences observed in both the average concentrations, and in some cases, the distribution over depth, in the monolith samples, is that some variation is due to the methods employed in the experiment. The monoliths were stored for a period, unfrozen, in a vertical rather than horizontal position. This has undoubtedly led to a greater degree of oxidation and the migration of pore water. However, if the variation was all down to migration within each monolith tin, we could reasonably expect to see double peaks of elemental concentrations, one in the last 20cm of the first monolith (30-50cm) and one in the last 20cm of the second monolith (80-100cm). This is not the case. Furthermore, the pore water concentrations of elements are very low, in part due to the higher than expected pH values obtained for the pore water in both the cores and monoliths. None tested below 5.5 pH, so metals like aluminium would not have been soluble at this value. It is hard to say which elements present were present in water soluble forms, as the test used cannot speciate elements or identify compounds. The results of the pH tests and the pore water ICP analysis are included in the project archive but not given any further consideration here for the reasons outlined above.

It is concluded therefore, that whilst experimental conditions might have caused some of the variations observed in the distribution of elements, this variation cannot adequately explain the changes noted, and taken in conjunction with the possible silting horizons noted in Core 4, and the base of the monolith, this points to some change in the hydrological regime associated with the trackway.

These conclusions have important implications for geophysical survey in similar lowland peat landscapes, particularly if the situation at Canada Farm is not unique, in terms of the archaeology influencing the hydrology of the peat. If future research could establish causal relationships between the archaeology and the chemical variations described above, then it might be possible to survey sites with this in mind, and detect archaeological remains by proxy means.

Chapter 10: Flag Fen, Cambridgeshire

Flag Fen is a Bronze Age site, though there is evidence that this part of the landscape has been occupied since the Neolithic (Pryor 1992b; 2001). The peatland part of the landscape has preserved one of the most spectacular Bronze Age sites in the UK. During a period of increasing wetness and peat growth in what would become the Cambridgeshire Fens a community built a large post alignment (the function remains unknown), with at least 5 rows of posts, in all about 15m across, out into the wettest part of the fens. It ran between the dry land at Fengate and the island of Northey. In the very wettest part of the fen basin, they constructed an enormous platform (see Figure 10.1). This platform may have been divided into smaller compartments, perhaps acting as family shrines. Early interpretations suggested this was a fortified settlement, like Biskupin in Poland (Coles & Coles 1989, 138), but examination of the evidence uncovered to date has shown that occupation did not take place. The current interpretation of the site is that it was used for the ritual destruction and deposition of objects into the bog, and may have formed part of human interactions with the landscape at a time of environmental and cultural change. Votive deposition appears to have continued in the Iron Age, after the post alignment and platform fell out of use, at least at the Cat's Water fen edge (Pryor 2001).

The site was discovered in 1982 during maintenance of the many drainage ditches in the fens; the land has been drained and in use for farming since the middle ages. Finds were not unknown, and ditch clearances were monitored by archaeologists as part of the South West Fen Dyke Survey Project, which ran from 1982-1986 (French & Pryor 1993). The post alignment has remained a linear feature in the landscape, even after it was buried under the peat; a Roman causeway closely follows its path, and later field divisions, based on old cattle droveways out onto the fens, mean the landscape divisions are still loosely based on an arrangement that goes back to the Neolithic.

Active excavations on the site ended in 1996, though there have been limited investigations since, and the majority of the platform was (it is hoped) preserved under an artificial lake, created by inserting a non permeable membrane into the ground to retain ground water. The edges of the platform are through to exist beyond this, but have only been located in a few trial trenches.

The post alignment has no special protection, and exists under land that has been taken out of arable use, and under managed meadow that is part of an archaeological park that extends over much of the site. Part of it is exposed and continuously wetted as part of the park, to educate the public and show the scale and context of the prehistoric timbers. In a recent publication on the site, Pryor, the excavator, expressed a great deal of pessimism about the continued survival of the site not protected under the artificial mere as a result of drainage and agriculture in the surrounding landscape (Pryor 2005).

The peat soils on the site are somewhat more complex than those overlying the Sweet Track. Though peat has been building up in the basin since the Early Bronze Age (Scaife, 2001, 367, 378) the sequence is complicated by marine and freshwater inundations, with interleaving of alluvial sediments. The area was then drained and cultivated (rather than simply being cut away during peat extraction); the loss of peat results from this dewatering rather than the removal of peat soils directly. The soils have been 'improved' and consolidated for agriculture.

Flag Fen therefore made an excellent case study site, with the archaeology being relatively well understood, and plenty of prior research about the soil profile, landscape evolution and hydrology (Pryor 1992a; G S B Prospection 1999; Pryor 2001; Heritage Management for England's Wetlands 2002; Lillie & Cheetham 2002; French 2003a). Limited geophysical surveys had been conducted by GSB for a Time Team episode about the site, but these concentrated on the dry land side of the site, and did not locate any waterlogged timbers. The site is not currently protected as a Scheduled Monument.

10.1 Area 1

10.1.1 Site background

This part of the site lies over the edge of the platform, confirmed in small trial excavations. It also contains the Roman causeway, some modern footpaths and service trenches, carrying water to the artificial lake, and a reconstructed Iron Age roundhouse. This roundhouse was in Grid 2 of the survey area, see Figure 10.2. The area is currently covered in short grass and is used for picnics by members of the

public and visiting school groups. It is often in use and an area of frequent pedestrian and vehicular traffic, as it is adjacent to the lake and museum.

The specific survey area is immediately adjacent to Cat's Water and The Mustdyke on two edges, and is bounded by footpaths (one of which lies over the former Roman Causeway); see Figure 10.2. (Pryor 1992a; GSB Prospection 1999; Pryor 2001; Lillie & Cheetham 2002; Heritage Management for England's Wetlands 2002)

10.1.2 Survey aims

Surveys in this part of the site were intended to try to locate the edge of the platform, which is believed to run somewhere through this part of the site, as shown in some small trial trenches. We wanted to see if any of the techniques were able to delimit the area of the waterlogged timbers, describe the peat basin at all, and map any later archaeology; the survey area is immediately adjacent to the Roman causeway.

10.1.3 Methods and instrument Settings

Fieldwork was undertaken from 3-7 September 2007. The preceding months and weeks had been much wetter than normal, but there was no rainfall during the week prior to or during the survey, and the weather was very warm and sunny. Towards the end of the work, the air was more humid and there were quite heavy dews overnight, but no significant moisture was added to the ground during the survey period.

Grids were laid out using the northern grid edge and edge of the grassed area as the baseline (laid out with a 100m tape). The southern grid pegs were then put in using an optical square from the baseline. Offset pegs were added near the reconstructed roundhouse to assist in surveying around this obstacle. The grids are numbered 1-3 working east to west, see Figure 115. Grid 2 contains the roundhouse, and Grid 3 is cut by a footpath not clearly indicated on the plan. Some of the techniques were only employed up to this footpath, others cease at a line of obstructing trees. The southwest corner of Grid 1 was not surveyed due to the presence of a steep slope into the previously excavated area and the Mustdyke, and a tree at the edge of the slope.

Table 7: Instruments employed at Flag Fen Area 1

Survey type	Instrument	Accessories/notes
Earth Resistance	Geoscan Research RM15	Used with GR MPX15 and a linear six probe array to allow simultaneous measurements of six different twin probe separations (.25, .5, .75, 1, 1,25 and 1.5m)
Magnetometry	Bartington DualGrad601 Gradiometer	Two 1m fluxgate gradiometers allowing rapid area coverage and hopefully better depth penetration than the BG FM36/256, which uses a .5m sensor separation.
Ground Penetrating Radar	Mala RAMAC X3M	Both 250 MHz and 500 MHz antennae employed to test signal penetration in thick peat soil. 100 MHz survey wheel for distances
Electromagnetic	Geonics EM38B	Used in vertical mode only due to expected depth of features.

Table 8: Instrument settings and survey methods at Flag Fen Area 1

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
RM15 with MPX15	1m	1m (six readings for each probe sep. at each point)	Zig-Zag	Slow reading speed to allow measurement to settle. 0.5 ohm resolution.
DualGrad 601	0.5m	0.125m	Parallel	0.1 nT resolution
Mala RAMAC 250MHz	0.5m	0.05m	Parallel	Set to 'medium'- 3.5m / 128 ns time window. 520 samples. Presumed velocity of 0.08m/ns
Mala RAMAC 500 MHz	0.5m	0.05m	Zig-Zag	Set to 'shallow'- 2.06m/ 49.2 ns time window. 512 samples. Presumed velocity of 0.08m/ns
EM38B	1m	1m	Zig-Zag	Both phases logged.

Once collected and downloaded the data was processed in GEOPLOT and GPR-SLICE as appropriate. The resistivity data was also exported from GEOPLOT and modified for use in Res2DInv to produce electrical resistance tomography (ERT) profiles, as discussed below. See Appendix A for a detailed log of the corrections and enhancements applied.

10.1.4 Results and interpretations

For the data plots, see Figures 10.3 to 14.44. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs. The interpretation plots were then digitised from the rectified data plots.

Description

Bartington DualGrad601 Survey: Figure 10.3

The results for this survey show a number of very small anomalies that are almost obscured by the presence of very large 'spikes' that dominate the data set, particularly on the junction between Grids 2 and 3. Once these have been reduced by processing and careful choice of plotting parameters a 'mottled' response is revealed with maculae of slightly enhanced response covering the survey area. In one area these resolve into something that could be termed an anomaly, a response different from the apparent background. In the centre of Grid 3, and proceeding towards the western extent of the surveyed area there is a zone of generally enhanced response. There is also possibly a linear trend to the maculae noted, running about 4m in from the northern edge of the survey area, running east-west and about 4m wide, but given the location of the unsurveyed areas and the noise from the spikes, it is impossible to say whether this is an anomaly or a reflection of the random background being made visible in a specific area.

Geoscan Research RM15/MPX15 survey: Figures 10.4 to 10.9

Broadly speaking, all six 'layers' of results show the same anomalies. There are areas of higher resistance at the eastern edge in Grid 1, and in the western part of the southern edge in Grid 3. In all six layers, but diminishing in extent and intensity with depth, there is a large high resistance anomaly running north/south across Grid 1. It is irregular in form, but in the higher levels at least approximates to a linear feature. In lower levels it is an oval whose terminals are well away from the Grid edges. There is also a very slight zone of higher resistance adjacent to the roundhouse in Grid 2. Aside from the anomaly, Grid 1 seems to have generally overall lower resistivity, and there is a zone of lower resistance running alongside (i.e. to the north of) the high resistance anomaly at the southern edge of Grid 3.

Geonics EM38B Survey

Vertical Quadrature response: Figure 10.10

The results show a generally conductive response, but with bands about 5-7m thick of less conductive material, running along the edges of the area surveyed, with the exception of the northern edge of Grid 1, which is highly conductive. At the border

between Grids 2 and 3 there is an area of disturbed response, showing both highly and weakly conductive results. There is a smaller area of mixed response in the centre of Grid 2. The centre of Grid 1 has an anomaly which is markedly less conductive than the surrounding soils.

Vertical Inphase response: Figure 10.11

The results show a reasonably uniform Magnetic Susceptibility across the surveyed area, with the exception of an area of noise at the junction between Grids 2 and 3, and Grid 3. Grid 3 shows a number of higher than the background MS responses. There is a strong response running diagonally from about 8m along the northern edge to about 5m in from the centre of the western edge of the Grid. This overlies a weaker but very extensive area of enhanced response running diagonally across the whole Grid from the North West corner to the south east. This anomaly is 5-10m wide.

Resistivity Inversions

Inversions were produced for the following lines of data in Grid 1:

Running east-west (across the survey traverses):

A- the first run of readings along the north side of Grid 1, to 20m (from the north-east corner of the survey)

B- the fifth run of readings in from the north side of Grid 1, to 20m

C- the ninth run of readings in from the north side of Grid 1, to 20m

D- the twelfth run of readings in from the north side of Grid 1, to 20m

E- the sixteenth run of readings in from the north side of Grid 1, to 20m

Running north-south (in line with the survey direction):

F- the fifth run of readings from the east side of Grid 1

G- the eighth run of readings from the east side of Grid 1

H- the eleventh run of readings from the east side of Grid 1

I- the fourteenth run of readings from the east side of Grid 1

J- the seventeenth run of readings from the east side of Grid 1

The reason these were not at equal intervals was to best capture the anomaly and to avoid parts of the survey that were 'dummy data' due to the presence of trees, steep slopes and the round house.

Table 9: Schematic of Inversion Profiles, Flag Fen Area 1

A				B				C				D				E			
A				B				C				D				E			
A				B				C				D				E			
A				B				C				D				E			
A,F	F	F	F	B,F	F	F	F	C, F	F	F	D, F	F	F	F	E, F	F	F	F	F
A				B				C				D				E			
A				B				C				D				E			
A,G	G	G	G	B,G	G	G	G	C,G	G	G	D,G	G	G	G	E,G	G	G	G	G
A				B				C				D				E			
A				B				C				D				E			
A,H	H	H	H	B,H	H	H	H	C,H	H	H	D,H	H	H	H	E,H	H	H	H	H
A				B				C				D				E			
A				B				C				D				E			
A, I	I	I	I	B,I	I	I	I	C,I	I	I	D,I	I	I	I	E,I	I	I	I	I
A				B				C				D				E			
A				B				C				D				E			
A, J	J	J	J	B,J	J	J	J	C,J	J	J	D,J	J	J	J	E,J	J	J	J	J
A				B				C				D				E			
A				B				C				D				E			
A				B				C				D				E			

North is to the left of the page, start of inversion line marked in grey. Each square represents a position in the 20x20m Grid, at 1m intervals where the 6 reading 'soundings' were taken.

Figure 10.12 shows the model blocks used for the inversions

Inversion A- Figure 10.13

This plot shows a thin high resistance zone at the immediate surface, perhaps just for the first 0.2- 0.3m, underlain by a much less resistive body. There is a spot at about 8.5m into the profile where this resistive layer dips lower, to about 0.4m. The underlying low resistance zone appears less resistive to the north of this 'dip', and more to the south.

Inversion B- Figure 10.14

This plot again shows a high resistance layer at the surface, to a depth of about 0.3m. The underlying area is generally low resistance, apart from for the first 2m of the profile where generally higher values persist to the depth of the survey. Then at about 8m to roughly 11.5m there is a higher resistance body that persists over depth, though it is stronger at the surface. The lowest resistance values in the underlying layer occur just to the north of this, and surprisingly at the top of the low resistance zone, from about 4m- 8m along the profile and 0.3-0.8m deep.

Inversion C- Figure 10.15

This plot is similar to B, though the high resistance anomaly is wider, from about 8m to 12.5. The high resistance layer at the surface is still present for the whole profile, but only to about 0.2m deep. The low resistance layer again has its lowest values just under this layer, but they occur both to the north and south of the high resistance feature.

Inversion D- Figure 10.16

This plot is very similar to Inversion C, apart from that the high resistance anomaly has shifted to the south, and occurs here between 10m- 16m, and also appears to be more intense. The north end of the profile seems to show the high resistance surface layer getting thicker as well, from about 18m to the edge of the grid.

Inversion E- Figure 10.17

This plot is quite different. There is still a band of higher values at the surface, but they contrast less with the underlying material for much of the profile. The higher resistance anomaly is still present, from about 10m to about 15, and it still occurs over the whole depth of the profile, but it contrasts less with the substrate. Rather than being generally low resistance, the substrate has two low resistance anomalies, the strongest from 7.5m to 9m along the profile and from 0.3-0.7m deep, and the other from 15.5m to 19.5m and from 0.7m deep to the base of the profile.

Inversion F- Figure 10.18

This profile shows, as before, a high resistance zone at the immediate surface, to about 0.2m depth, underlain by a low resistance body to about 1.3m depth, below which the resistivity increases again slightly to the bottom of the profile. At about 14m along the profile, the high resistance zone at the surface becomes much deeper, running to the bottom of the profile for the remaining 6m of the transect.

Inversion G- Figure 10.19

In this profile the high resistance surface is underlain by a low resistance body for the whole of the profile. For the first 5m, this high resistance layer is roughly 0.7m deep,

gradually tapering upwards to be about 0.25m deep for the rest of the profile. The low resistance body goes from the base of this to about 1.3m deep then the resistance gradually increases with depth to the base of the profile.

Inversion H- Figure 10.20

This profile is quite different from the previous two. There is a high resistance zone at the top of the profile, and for the first 4 and last 4 meters it is underlain by a low resistance zone. This layer is about 0.5m thick. In the centre of the profile, from 4m to 16m and extending for the full depth of the profile there is a pronounced high resistance anomaly. Unlike the other anomalies described so far it is not most intense at the surface; the highest resistance values are found from about 10.5m to 15.5m along the profile and from 0.3m to 0.7m deep.

Inversion I- Figure 10.21

This plot shows a high resistance band at the surface to about 0.5m deep, but with much lower values than previously encountered. This continues across the whole profile and is underlain by a low resistance zone that extends the full depth of the profile. There is a high resistance anomaly at about 12m to 16m that extends the full depth of the profile. The high resistance zone to the south of this (for the last 4m of the profile) is thicker, about 0.7m deep, and the underlying low resistance area is less pronounced.

Inversion J- Figure 10.22

This plot shows a high resistance band right at the surface, to about 0.5m and with less intensity than previously observed. At about 12m along the profile the base of this layer dips to about 1m, before returning to its previous depth.

Radar surveys

250MHz Antenna

This description (and Figure 10.54), is derived from all of the timeslice plots, which are presented as Figures 10.24 to 10.33. The anomalies described have numbers, these correspond to the plan. The depths given are based on an assumed radar velocity of 0.07m/ns for waterlogged peat soils; these are shown in Figure 10.23

In timeslices 1-17, with traces showing down to 19, (0-1.64m/ 1.82m) there is a reflecting anomaly (1) that runs parallel to the southern edge of the survey, but ceases about 1m before the end of the runs. At its widest points (to the western end of it's extent) it is more than 2m wide. At timeslices 3&4 (0.18-0.45m) and at 8-19 (0.641.82m) there is a disturbance in the response about 2m long and about 2-3m to the west of the gap in the survey necessitated by the reconstructed roundhouse.

A very small reflection that appears to be part of anomaly (2) shows in timeslice 1, but there is a more consistent anomaly (2) present from timeslice 2-13 (0.09-1.27m). This starts in roughly the centre of Grid 1, and the focus of it moves north and east over depth, but for most of the visibility of this anomaly it is a long thin oval.

There is a less intense anomalous response in a semi circular shape around the northern edge of the gap in the survey for the roundhouse (3). There is a bright spot of strong reflection that forms the westernmost part of this anomaly that is present from timeslices 10 (0.8m) to the base of the survey (2.8m). The rest of the slightly less intense curving disturbance in the response is present from timeslices 6-10 (0.461.0m).

There is a strong but short lived reflector, which is very abrupt and linear, about 0.5 wide that diagonally cuts across the north west corner of the survey (4). It shows in timeslices 1-3 (0-0.36m). There are faint reflections forming a similarly shaped anomaly in the same location as much greater depth, showing in slices 13-25 (1.12.3m).

There is a small reflecting anomaly to the east side of the gap in the survey due to the roundhouse (5) which appears in slices 1-6 (0-0.6m) where it seems to merge into anomaly (3).

There is a disturbance in the response about 5m in from the southern grid edge along the intersection between Grids two and three that shows in slices 3-7 (0.18-0.72m) that at its strongest seems to be rectangular (in slices 4&5, 0.27-0.54m). It is about 2m across as a maximum.

500MHz Antenna

This description (and Figure 10.55), is derived from all of the timeslice plots, which are presented as Figure s 10.35 to 10.44. The anomalies described have numbers, these correspond to the plan. The depths given are based on an assumed radar velocity of 0.07m/ns and are shown as Figure 10.34

There is a reflecting anomaly in the northwest corner of the surveyed area (1) that appears in slices 1-30 (0-1.35m) but is patchy in appearance from slice 22 (1m) downwards. It occupies a triangle with one edge running about 2.5m south from the north west corner and one edge running about 10m east of the same corner.

There is a strong reflecting anomaly that cuts across the south west corner of the area surveyed (2) and is about 2m wide. It appears in slices 1-9, though is patchy from 6 downwards (0-0.44m / 0.31m).

There is a substantial reflecting anomaly in roughly the centre of Grid 1 that starts as a small reflection but over depth extends north and east to the edge of the area surveyed before its base is reached (3). The strongest part of the anomaly also moves northeast over depth. In slices 1-3 only a small southern part of the anomaly is visible (0-0.18m), but from slice 4 the full extent as shown in Figure 10.55 is producing a response, which continues to slice 16 (0.18-0.74m).

There is a small, strong but discrete anomaly immediately to the north of the roundhouse (4) which shows from slices 2-33, but fading from 30 (0.4-1.48/ 1.35m). There is a noisy patch in the response just to the east of this from slices 13-20 (0.50.92m).

At the intersection of Grids 2 and 3, roughly midway along the line between the grids there is a noisy patch that for part of the response has very a very rectangular form (5). The noise appears in slices 6-12 (0.22-0.57m), but the rectangular sides show most strongly in slices 8-11 (0.3-0.5m). This anomaly is about 3x2m and is about 1m north of anomaly (6) in the 250MHz data (see above, and Figure 10.54).

Interpretation

Bartington DualGrad601 survey- Figure 10.45

Unexpectedly (Burton & Hodgson 1987; Gaffney & Gater 1993; David 1995; Clark 1996; Martin 2002; Challands 2003; Dalan 2006), there does appear to be some variation in the magnetic enhancement of the soils on the site. Unfortunately, the presence of large ferrous spikes (probably due to materials left in the back fill of a test pit at the junction between Grid 2 and 3, and surface materials related to the presence of picnic tables and the roundhouse) make it hard to resolve these spatially. There is a spread of enhanced response along the northern edge of the area surveyed, but whether this is of archaeological significance or a matter of geology is uncertain. Furthermore, the apparent restriction of this feature to this area may well be a product of the areas that were surveyed and the noise from the ferrous material, rather than reflecting accurately the spatial extent of the anomaly. The ferrous spikes mask the more subtle responses in the areas they occur and processing can only reduce them to a degree. In Grid 3, at the centre of the western edge of the grid, there is a positive anomaly that is potentially archaeological, even though it is the same area as the footpath; the footpath is magnetically enhanced (possible due to the heating of materials used for it) as seen in the Inphase EM survey, but it does not show in the gradiometry as it is a thin lens of material, and gradiometers do not normally detect these. The gradiometry has shed little light on the archaeology, but does seem to detect anomalies in these soils and has been very useful in assisting the interpretation of the other techniques. In areas with fewer disturbances it might have more success.

Geoscan Research RM15/MPX15 survey- Figures 10.46 to 10.51

The multiplexed resistivity survey in theory shows horizontal slices through the ground at the same depth as the probe separation for each layer. The probe separations are given above. The real picture is more complex than this. As each probe separation is measuring across a different volume of soil, calculations must be made to correct for this. Once converted to apparent resistivity in this way, it is possible to make numerical comparisons between the responses. Even this does not resolve the 'true' depths and extents of anomalies however, as the whole block of soil is measured, not just the location at depth. Inversion modelling is needed to resolve the influence the upper volumes have on the lower levels. Inversion modelling was carried out on specific areas of this survey, to allow better understanding of the spatial extents and

intensity of the large anomaly showing at all depths in Grid 1. These are discussed below.

Taking on board the issues above, the simple slices generated in GEOPLOT still have some archaeologically interesting anomalies. The large high resistance anomaly in Grid 1 seems to be in the same place as the parch mark noted in the topographic survey. There is a hollow there, and a tree at the centre of the hollow, parch mark and anomaly. Considering these results *without* the inversions it is very difficult to say whether this anomaly is differential drying of the peat, perhaps caused by the tree's root complex, or whether it is an archaeological feature, perhaps a spur from the Roman Causeway. The area of high resistance at the south east corner of Grid 1 is adjacent to a very steep slope down into the area of the former excavations. It seems this exposure is allowing the peat to dry out more in the immediate vicinity of the cut, due to the increased surface area. The anomaly immediately north of the roundhouse is more problematic. It appears to diminish in extent and intensity with depth (but see cautions above). There are also ferrous 'spikes' in the same area showing in both the gradiometer and EM surveys. It is likely therefore, that this is modern disturbance related to the construction of the roundhouse. There are no test pits or trial trenches noted in this location.

The seemingly associated low and high resistance anomalies present at the southern edge of Grid 3 are provisionally interpreted as being related to the Roman Causeway that they run very close to. Early examinations of the GPR results show a response typical of a ditch next to the road which shows very clearly. The high resistance anomaly could either be the modern footpath or the causeway as the two are contiguous for a time then diverge slightly. The Inphase results for the EM survey show a large spread of enhanced magnetic susceptibility in a similar area to the slight low resistance anomaly, which could indicate the presence of magnetically enhanced soils in a ditch. Unfortunately the ferrous spikes in the gradiometer survey are in this location, so a further source of confirmation is lost.

The resistance survey was successful in that it has identified anomalies of possible archaeological interest, and the method has proved suitable for making inversion models to allow better interpretations of anomalies at depth.

Geonics EM38B survey

Vertical quadrature response: **Figure 10.52**

The quadrature response is a measure of the conductivity of the soil, so, as expected the results mirror the general resistivity response, with some interesting differences. The EM38 does not need to be driven into the ground, so it was possible to survey over the footpath that crosses the edge of Grid 3 which revealed a large low conductivity anomaly. The low resistance anomaly is not echoed, instead there is a more general low *conductivity* anomaly in the same area. This is possibly due to the differing depth sensitivities of the two instruments. This survey also picked up a low conductivity anomaly at the northern edge of Grids 2 and 3 that does not show in the resistivity surveys. There is also a general zone of slightly higher conductivity in the centre of the area surveyed. As this instrument is most sensitive at the near surface, this effect is likely to be due to differential surface drying of the peat, the drying being more pronounced adjacent to footpaths and cut features, such as the eastern edge of Grid 1.

There are also two areas of 'noise', very disturbed high and low readings well outside of the normal range. These match up with the ferrous spikes in the gradiometer data. The conductivity results taken with the gradiometer results show these objects to be both magnetic and conducting, and so likely to be modern metals, rather than bronze.

Vertical inphase response: Figure 10.53

As has previously been stated, peat soils are not expected to have strong magnetic susceptibility enhancement potential so the results of this survey were somewhat unexpected.

The 'spike' feature at the juncture between Grid 2 and Grid 3 is almost certainly due to signal leak between this part of the response and the very high conductivity responses noted above, furthering the case for this material to be modern ferrous rubbish.

There are two areas of enhanced MS. One seems to run for the first part of the footpath across the area, probably reflecting a heat treated material used in its construction. The other area is a wide band extending from the west to east side of the

grid and is at its widest 10m across. This seems to correspond to two areas of low resistance picked up in the EM38 survey and the resistivity survey. This could indicate a ditch that has been filled with anthropogenically enhanced soils. However, the dimensions do not seem to be correct, 10m would be far too wide for the ditch adjacent to a Roman causeway. Another possible explanation is that the ground here has been levelled with the import of soil from elsewhere, and given the generally low MS response, any soil that had even slight enhancement would show as an anomaly. Furthermore, this response is not present in the gradiometer results, which indicates this might be quite a thin layer as a ditch fill would be expected to show. Unfortunately the ferrous spike in the area has hindered any further conclusions being drawn as it may be masking the gradiometer response in this vicinity.

The area which seems slightly reduced in comparison with the background to the north of the roundhouse is in a location already interpreted as having some degree of modern disturbance. It is possible that if a trench was backfilled with soil from elsewhere, or that soil from further down the profile (and having a lower MS) was brought to the surface by the disturbance.

The EM38B survey was successful. It identified a number of anomalies, some of which have possible archaeological interpretations. It was also able to deal with footpaths and other obstacles, allowing a greater area to be covered than the other techniques. The results have been particularly useful in conjunction with the other tests to provide confirmation of the reasons for some of the responses, or different results due to differing effective depths.

Resistivity inversions

The inversions allow a more accurate picture of the depths of any anomalies in the subsurface to be identified. They will be discussed as a whole body of data here rather than individually.

The profiles that cut across the anomaly (A-E) being investigated clearly show it in the expected locations. They also show a very high resistance zone at the top of the profile for roughly the first 30cm of the subsurface. They generally show the high resistance anomaly continuing for the full depth range of the survey, but the strength

of it weakening over depth. Generally speaking, they show the soils below about 0.3m deep are very low resistance by comparison, and that this seems to continue to the base of the profiles. No new interpretations for this anomaly are suggested by the inversions, but they do rule out some of the possibilities raised by the initial plans of the readings, displayed as normal area twin probe surveys over different probe separations in the first part of this discussion. The inversions show that there is depth to this anomaly and that it is not being produced by a lens of highly resistant material at the immediate surface. This still leaves several possible interpretations; the two most likely being that this anomaly is either the root mass of a tree (or localised drying associated with this), or that it is some sort of offshoot of the Roman causeway. The inversions do not allow a conclusion on this. However, they do compliment the radar data, and make a useful contribution to understanding the results of the radar surveys.

GPR surveys
250MHz survey- Figure 10.54
As can been seen from Figure 10.54, the 250MHz survey method (parallel) allowed a greater area beyond the survey grids to be covered to try to better establish the context of the archaeology.

Anomaly (1) is interpreted as being the Roman causeway (and later roads on the same alignment), especially given its slight displacement from the modern path. The Roman causeway at this location, and in the exposure on the dykeside, is known to lie at the surface rather than being buried in soils or peat. It is important to note that this is further south, and quite distinct from the magnetic and resistivity anomalies noted in the southern part of Grid 3. This area of higher magnetic susceptibility and low / high resistance does however seem to be associated. Given this association, and with new information supplied by Mike Webber, the site archaeologist, (pers. com. 2008) following an exposure through the road for some site maintenance work, this low resistance, magnetically enhanced zone is interpreted as being the more deeply cut end or turning zone of ploughing. Evidence from elsewhere on the site shows that the Roman causeway continued to be used as a boundary feature in the landscape. Here it would appear that it was an obstacle to ploughing, so ploughs were turned at this boundary, and perhaps cut more deeply or encouraged

material to accumulate. If the fields were being improved with refuse (ash and midden deposits) this would explain the slight magnetic enhancement in this part of the site. This also explains the apparent holes or damage to this feature in places, if ploughing has been continued right up to where it becomes impossible due to the compacted road surface.

Anomaly (2) is the one that inversion transects were taken across to try to understand it better. The radar survey has a greater depth than the resistivity and the radar shows that anomaly 'bottoms out' at about 1.3m. The radar survey also seems to indicate that the strongest part of it slopes downwards in a north-easterly direction. This anomaly is very hard to interpret. It continues over some depth in the soils but is present from the surface. The elongated nature of the feature disinclines an interpretation of it being the tree's roots; a natural root mass would be more spherical, and less well-defined.

Anomalies (3) and (5) are interpreted as being related to the construction of the roundhouse, or to excavations on the site of it prior to its erection. They conform too well with the outline of the building to be other, older features interrupted by it.

Anomaly (4) is interpreted as being a strong reflection from the modern footpath that crosses that corner of the survey.

Anomaly (6) is associated with noise in both of the magnetic surveys. This was interpreted as being modern ferrous backfill in an old excavation trench (see above), and the general shape and location of this anomaly confirms that interpretation.

500MHz survey Figure 10.55
Anomalies (1) and (2) are interpreted as being strong reflections from modern paths on the site, or localised soil changes in the areas adjacent to them.

As previously discussed, the cause of the reflecting anomaly in Grid 1 (anomaly (3)) is very difficult to establish with certainty. The depth to the base of this feature in this survey does not agree with that in the 250MHz survey. There are a few possible explanations for this. The first and most likely is that the antenna depth estimates need

better calibration against both the central frequency of the antenna and the soil types and how they vary over depth. The other, and not mutually exclusive explanation, is that in these soils and with this very dry zone over a wet zone, the signal from this antenna attenuates very rapidly, and the feature does extend deeper than 0.75m, but is not producing reflections strong enough to get back to the antenna.

This could also explain why anomaly (4) was the only parallel to the large noisy zone around the roundhouse noted in the 250MHz survey (anomalies (3) and (5) in Figure 5); these showed below the 'dry' zone and as such might not have been picked up by The 250MHz antenna. Anomaly (4) is interpreted in the same way, however, as being related to the roundhouse or its construction due to its physical proximity to these other anomalous responses.

Anomaly (5) is definitely separate from anomaly (6) in the 250MHz survey, but has the same association with noisy responses in the gradiometry and EM surveys . The rectangular nature of the feature was picked up quite clearly in this survey and it is firmly interpreted as being an old excavation trench with modern ferrous material in the backfill. This suggests that there are two small trenches quite close to each other. Even allowing for mis-calibrations of the survey wheel, these anomalies do appear to be distinct, even though they show in two different surveys, (rather than both showing in both).

Nothing that could be interpreted as the platform was noted in the GPR surveys, though the lower slices of each survey do seem to become more generally 'noisy'. This noise is likely to be due to signal loss and the gaining process rather than any possible interpretation of timbers being detected.

11.1.5 Case-study specific conclusions

The gradiometry and inphase EM were a lot more useful than had been suspected, particularly when used together and in consideration of the resistivity/quadrature results, helping to resolve important questions about some of the 'noise' in the data. Several anomalies of potential archaeological significance were identified, and it was also demonstrated that both the EM and the resistivity work have potential as monitoring tools to look at de-watering in key areas of the site.

The surveys failed to locate an edge to the platform. There are a number of possible reasons for this. Firstly, from detailed examination of the mapping for the site, it appears the only trench which located the 'edge' in this position was the trial trench located at the junction between Grid 2 and 3, which was apparently backfilled with some ferrous rubbish. It is therefore possible that the 'edge' is not actually present within the survey area. If it is, it is possible that it is a not discrete or continuous feature and more a gradual change in the density of timbers. Such a gradual change would be hard to detect, even without the added problems of waterlogging.

Furthermore, as the above shows, this particular part of the site has a lot of modern disturbance related to the roundhouse, museum and general use by the visitors. This has produced modern 'noise' in the results, which potentially masks more subtle features. The area also seems to be quite dry. It is possible that the platform has been subject to dewatering in this area, and so no longer survives as a large body below the surface. Conversely, it could be there but the nature of it (e.g. a continuous surface) makes it invisible to the majority of these techniques.

The resistivity inversions confirm two things not detectable by other means, that the first 0.3m of the soils in this part of the site were very dry at the time of the survey, and that the anomaly noted in Grid 1 does have some depth to it, rather than being an artefact of particularly high surface resistances.

The radar surveys have helped understand this anomaly as well, confirming that it does exist over depth and giving more information about its characteristics in three dimensions. However, none of this allows a definitive interpretation to be arrived at. They do clearly show the anomaly does not 'join' the Roman causeway, so interpretation of this anomaly remains ambiguous.

The radar survey was also able to identify areas of former excavation and confirm the interpretation of spiking in the gradiometer and EM surveys as modern ferrous material contained in the backfill. The identification of the Roman road and possible ploughing damage to it has helped to interpret the surveys previously reported on, concluding that the magnetic enhancement and low resistance anomaly in the south of

Grid 3 is evidence of a ploughing headland, with the fields aligned on the Roman causeway.

Both radar surveys also picked up anomalies that seem to be associated with the roundhouse, possibly from the digging of the post-holes and foundation trenches, or perhaps with the eaves drip, as the structure has been standing more than a decade.

No sign of the platform, or an edge to it was picked up in any of the techniques reported on here. However, the results from the inversions allow some insight into why that might be. They identified a highly resistant zone right at the surface where the soils had become very dry. With the depth the archaeology is expected at, combined with the very wet subsurface, it is possible that any reflections from the platform or associated features are too weak to cross this interface into the dry zone, and are simply lost. It is also possible that this strong dry zone is making the environment even more attenuative by absorbing and internally refracting a lot of the radar energy. If the platform does not have a definite 'edge' then this increases the likelihood that it will not be visible in the radar response. The description of the trench in this area does not clarify the matter (Pryor 2001, 85).

Despite the non-detection of the platform, these surveys were very successful in their other objectives; which were to explore the responses and usefulness of a variety of geophysical techniques within a lowland peat environment, where waterlogged wooden remains were expected. What this survey has shown is that in areas with modern disturbance, and where there is significant surface drying of the peat, these techniques and these radar frequencies do not seem to detect waterlogged wood.

Another important conclusion is that in combination, geophysical techniques give more information than one technique alone, with results from one confirming or helping to explain the response of another.

A record of the old excavation trench noted in the surveys was located (Pryor, 2001, 85); it is known as 'Area 3' in the Flag Fen records system, but no plan of the trench was available. It had apparently been opened to check ground conditions before some

development on site took place, and that substantial timbers of planking were present, but there is no specific mention of an 'edge' to the platform being found.

10.2 Area 2

10.2.1 Site background

This survey was located over the known line of an alignment of posts built between the large platform in the wettest part of the fen and dry land to the east and west. The post alignment is made up of at least 5 lines of massive timbers sunk into the fen, with a mass of associated timbers that survive in the waterlogged soils. Excavation has revealed it is 10-15m wide, at least. The survey area has some medieval and later cultivation of the upper soils, but no noted features from any other period. The archaeology is at a depth of about 1-2m below the surface at the west end of the area, but possibly rises following the fen basin as it rises up towards Northey Island. (Taylor & Pryor 1990; Pryor 1992a; 2001). The structure was built and maintained over a period of 400 years from the late first half of the 13th Century BC to around 924 BC, though deposition of votive objects seems to have continued into the Iron Age on some parts of the site (Pryor, 2001, 421).

The presence of the timbers has been confirmed by excavations at both ends of the survey area; see Figure 10.56.

The area was a managed hay meadow at the time of survey, and was occasionally used as a display/gathering space for events in the archaeological park. Since the geophysical surveys, but before the ground-truthing work, replica posts and a dip well for water-table and quality monitoring have been installed in the centre of the survey area.

10.2.2 Survey aims

The aims of the surveys in this particular area were to detect and delimit the timbers of the post alignment, and if possible, learn more about the form of the peat basin they were built in. Given observations in Area 1, we also wished to see if it was possible to make an assessment of the hydrology and state of preservation of the lower sediments containing the archaeology.

10.2.3 Methods and Instrument Settings

Fieldwork took place from 17-21 May 2008. Conditions preceding the fieldwork period had been generally dry, but rain fell on the 16th, and continued through to the morning of the 17th. The rest of the period remained dry and, though the long grass on the field was wet for about 24 hours after the rain stopped, the ground remained relatively dried out, with no mud or surface water. Deep cracks in the soil were evident across the survey area.

The vegetation is primarily meadow grasses that are actively managed and cut reasonably regularly (but not kept 'lawn' short). The surveys delayed a scheduled cutting so the vegetation was at its general maximum at the time of the work.

An old field boundary was included in the survey area. This runs through the lower third of Grids 1 and 3 from east to west. It has been removed at some point in the recent past and is still visible on the surface as there is an area, about 3m wide at maximum extent, with very different vegetation typical of broken ground; nettles and brambles. There are one or two remnants of a hawthorn hedge but these did not prove an obstacle to survey. This boundary is shown on the mapping data as the blue lines within the survey area shown in Figure 10.56 but the only part of this system still visible was the remnant of the hedge, as described, in Grids 1 & 3. There was no surface evidence of the other boundaries. G S B (1999) surveyed part of this area with resistivity equipment, but only detected geological changes.

For this phase of the work on the site, 6 20m x 20 m grids were located over the known location of the post alignment; a massive alignment of timbers over 15m wide that runs through the site, as shown in Figure 10.56. The centre line of the grids runs along the supposed centre line of the archaeology. With a smaller target this could risk the target being 'missed' in edge or end of line effects, but given how substantial the archaeology is known to be, this centre placing was necessary to ensure the edges of the archaeology could be reasonably expected to lie within the survey area, with a substantial error margin to either side of this central line. In addition, the radar data was collected as a set of 40m runs zigzagging across the 60m x 40m survey area, eliminating this centre line issue for those two datasets.

Table 10: Instruments used at Flag Fen Area 2

Survey type	Instrument	Accessories/notes
Resistivity	Geoscan Research RM15 with MPX15	Twin probe configuration with multiple probe spacings logged automatically at each station: 0.25, .0.5, 0.75, 1.0, 1.25 and 1.5m separation respectively.
Magnetometry (gradiometer)	Bartington Dual Grad 601	
Electro-Magnetic	Geonics EM38B	Used coils in vertical orientation. Both inphase and quadrature components of the response logged.
Ground Penetrating Radar	Mala RAMAC GPR	500 and 250 MHz antennae employed, 100 MHz survey wheel used to measure distances.

Table 11: Instrument settings and survey methods at Flag Fen Area 2

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
RM15	0.5m	0.5m	Zig-Zag	0.5 ohm resolution
FM36	0.5m	0.5m	Parallel	0.1 nT resolution
Mala RAMAC 500 MHz	0.5m	0.05m	Zig-Zag	Depth setting: Shallow: 31μs time window. 512 samples. Presumed velocity of 0.07/ns
250 MHz	0.5m	0.05m	Zig-Zag	Depth Setting: Medium 128μs time window. 520 samples. Presumed velocity of 0.07m/ns.
EM38B	1m	1m	Zig-Zag	Both inphase and quadrature responses logged.

Once collected and downloaded the data was processed in GEOPLOT and GPR-SLICE as appropriate. See Appendix A for a detailed log of the corrections and enhancements applied.

10.2.4 Results and interpretations

For the data plots, see Figures 10.57 to 10.97. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs. The interpretation plots were then digitised from the rectified data plots.

Notes in parenthesis refer to the numbered anomalies in the accompanying interpretation plots (Figures 10.98 to 10.108).

Description

RM15 multiplexed resistivity survey

Probe separation A (0.25m) - Figure 10.57

The raw field data ranged from 7.3 ohms to 203.35 ohms, with an average of 24.17 giving this dataset a speckled appearance. No coherent features are identifiable in the data, but there is a trend towards higher resistivity readings in the southern half of the survey, but especially Grids 1 and 5. This area is not sharply defined, and lacking in cohesion.

Probe separation B (0.5m) - Figure 10.58

The raw field data ranged from -2.15 ohms (an error reading caused by poor probe contacts) to 178.35 ohms, with an average of 10.8 ohms. Again, this data has a speckled appearance and there are no coherent features identifiable. As with the previous data, there is a zone of generally higher resistance values that covers the south-western part of the survey. It covers almost all of Grids 1 and 5, and about half of Grids 2 and 3. Again, it is not sharply bounded and lacks cohesion.

Probe separation C (0.75m) - Figure 10.59

The raw field data ranged from -2.5 ohms (again, an error) to 148.9 ohms, with an average of 6.99 ohms. It is similar to the datasets described above, except that the higher resistance area is more to the south than the west, covering all of Grids 1 and 3, the northern 2/3 of Grid 5 and the southern 1/3 of Grid 2. It is slightly more 'definite' than at the previous two depths.

Probe separation D (1.0m) - Figure 10.60

The raw field data had a range of 0.85 ohms to 12.9 ohms, and was much less affected by poor probe contacts, with an average of 4.9ohms. The higher resistance area is more easily identified, though still not forming any coherent features. It covers all of Grid 1 and 3, and the northern 2/3 of Grid 5, with a much less intense crescent shaped extension into Grid 6, which in terms of area covers about 50% of the grid. There is also a small area of higher resistance readings in the south east corner of Grid 2, about 2.5 x 5m in size.

Probe separation E (1.25m) - Figure 10.61

The raw field data at this depth/ separation exhibits a very wide range, from -39.8 ohms to 171.5 ohms (as a result of poor probe contacts), with an average of 4.5 ohms. Once the errors were corrected, the high resistance area was easily identified, though the edges of it remain soft, rather than sharply delineated, and there are still no coherent features. It forms a meandering, wide (about 10m) anomaly that snakes though Grids 1 and 3, before becoming a wider (at most about 15m) crescent shaped anomaly that takes up most of Grids 5 and 6, with an end just protruding into the southern half of Grid 4.

Probe separation F (1.5m) - Figure 10.62

This data also had probe contact issues, with the raw field data ranging from -11.3 ohms to 169.05 ohms, and an average of 3.47 ohms. Once this was corrected for, three areas of generally higher readings were visible, but again they were not sharply delineated and there were no coherent features. The largest area is in the east part of the survey and is roughly 15 x 30m running in the centres of Grids 5 and 6. There is another area that takes up almost all of Grid 3 apart from the northwest quarter, with a 5m offshoot into the eastern side of Grid 1, and one smaller area in the northwest corner of Grid 1.

DualGrad 601 gradiometry survey- Figure 10.63

The survey area was contaminated in places by very magnetic modern rubbish, so the range of the data as collected was off the scale, both positive and negative, but the average was -2.67nT. Once the dataset had been corrected as much as possible, the only features of note were a general trend of alternating negative/ positive linear anomalies, only about 1-2m apart, with the enhanced lines being 1m or less wide, running diagonally south-west to north-east across the survey area, but particularly obvious in Grids 2, 4 and 6. There were also concentrations of spikes in Grids 1 and 3, and some seeming to run alongside the linear banding in Grids 5 and 6, and at the terminus of one of the bands in Grid 4.

EM38 survey

Vertical quadrature phase response- Figure 10.64

The raw field data showed a range of -8.82mS/m to 51.2 mS/m with an average of 37.33 mS/m. The negative response is likely to be due to 'error' readings from highly conductive and highly susceptible modern ferrous material at the surface. Once the data was corrected, a few distinct areas appeared either more conductive or less than the general background readings. There was a diffuse area of low conductivity covering all of Grid 3 and the southern 2/3 of Grid 1. This is a trend towards lower values, rather than a sharply delineated anomaly. There was a zone of higher conductivity, more sharply defined around the eastern and northern edge of Grid 6, the northern edge of Grid 4 and the eastern and southern edge of Grid 5, about 5-8m wide at its widest. There was also a roughly 5x5m area of higher conductivity values in the southwest corner of Grid 6. None of these areas form any coherent features as such, and are generally soft edged.

Vertical inphase response- Figure 10.65

Once converted to ppm, the raw data range from -1675ppm to 2922ppm (the negative values are not an error, this is a relative measurement, against a zero point on site, where the instrument is balanced, much like a magnetometer). The average was 282.6ppm. The wide range is likely to be due to the presence of highly conductive material causing interference in the inphase component of the response. Once the data was corrected for this as far as possible, one strong anomaly became visible, an distinct and discrete area of reduced MS, running east-west through the centre of Grid 1 then dog legging slightly to the south as it runs about halfway across Grid 3. This anomaly is at most about 3m wide. There are also some areas of apparently raised MS, along the northern edge of the survey area, only about 1m wide across the top of Grid 4 but considerably wider across Grids 2 and 6, widening to cover the northern half of Grid 6. There is also a smaller, narrow enhanced area, about 10 x 5 at maximum extents running in the centre of the southern edge of Grid 1.

GPR 500 MHz survey- Figures 10.67 to 10.81

As these results are rather more complex, with anomalies appearing at different depths and over/underlying each other, in Figure 10.107 they have been numbered for

ease of description, and are discussed as a whole here, rather than individual slices. Figure 10.66 shows the estimated depth of each timeslice.

1. Anomaly 1 is a strong linear reflector present at high intensity from slice 1 to 6 (0-6.5ns/ 0-0.2m), with some strong responses still visible down to slice 9 (9.5ns/0.33m). There is then a disturbed character to the response in this zone down to slice 30 (29ns/1.04m). The anomaly runs at a slight angle, wnw/ese through the centre of Grid 1 and on down through the lower 1/3 of Grid 3. At its widest it is about 2.5m wide and it is about 40m long.

2. Anomaly 2 is another linear anomaly with quite strong reflections. It is visible from slices 1-4 (0-4.5ns/0-0.16m) as a strong feature, then faintly to slice 7 7.5ns/0.25m. It runs through the centre line of Grids 3 and 4, on the same axis as the survey grid but not quite north-south. It is much less substantial than anomaly 1, but almost intersects with it at its most southerly point. It is less than 1m wide for the majority of its length. It does not re-appear or continue beyond the line of anomaly 1 but appears to at least reach the northern edge of Grid 4.

3. Anomaly 3 is a group of alternating linear high/low amplitude trends, running diagonally through the western part of Grid 6. They are at a sharper nnw/sse angle than anomaly 2 and appear in slices 1-7 (0-7.5/0-0.25m), intermittently. There is an outlier in the eastern part of Grid 4 on the same alignment.

4. Anomaly 4 is a small high amplitude reflector that appears in slices 4-13 (3-13.5ns/0.0-0.47m). It is at most 1m in diameter. It lies to the south and east of the centre of Grid 6.

5. Anomaly 5 is present, intermittently in slices 1-13 (0-13.5ns/0-0.47m), showing initially (to slice 4 (4.5ns/0.16m) as an area of reduced amplitude response, then as a higher amplitude signal. It runs along the northern edge of the survey and at its widest extends about 2.5m south from this edge.

6. Anomaly 6 lies under anomaly 2. It is a strong high amplitude reflector visible in slices 19-23 (17.8-23.3ns/0.62-0.82m). It lies just to the north of the centre of Grid 3 and is about 3m x 1m with the long axis oriented roughly north-south.

7. Anomaly 7 also lies under or adjacent to anomaly 2. It appears in slices 7-9 (6-9.5ns/0.2-0.33m) though there is perhaps the start of it in slice 6 (5ns/0.17m). It is about 1m in diameter and lies in roughly the centre of Grid 4.

8. Anomaly 8 is a second group of alternating linear high/low amplitude responses. These are on a different alignment to anomaly 3, running ne-sw through the centre of Grid 2. They appear in slices 1 and 2 (0-2.5ns/0-0.09m), and cover a band about 5m wide.

9. Anomaly 9 is a lower amplitude area that extends about 1m (maximum) to the north and south of the central division between the two rows of Grids. It is visible from slice 1-3 (0-3.5ns/0-0.12m) then shows as a very faint higher amplitude area in slices 4-5 (3-5.5ns/0.1-0.19m).

GPR 250 MHz survey- Figures 10.83 to 10.97

These results are dealt with as numbered anomalies, as above, following the scheme presented in Figure 10.108. As before, the dataset is treated as a whole with the depth estimated for each slice shown in Figure 10.82.

1. Anomaly 1 is a substantial high amplitude reflection showing in slices 1-4 consistently (0-18.12ns/0-0.63m) then very intermittently to the base of the results in slice 30 (121.6ns/4.26m). It is at its widest about 3m across and about 40m long running wnw-ese in the bottom 1/3 of Grids 1 and 3.

2. Anomaly 2 is also a linear high amplitude response, showing in slices 1-3 (0-14.13ns/0-0.49m). It is less than 1m wide for most of its length and runs on a nnw-sse alignment through the centre of Grid 4 and extending to almost the centre of Grid 3.

3. Anomaly 3 is a collection of faint alternating higher and lower amplitude trends, indicated by solid lines in Figure 10.82. These appear from slice 1-2 (0-10.14ns/0-0.14m). They are quite widely spaced with one higher amplitude line occurring roughly every 3-4m. This pattern covers the western 2/3 of Grid 6, running on a roughly nnw-sse alignment, but at a sharper angle than anomaly 2. The ends of the lines extend down into Grid 5.

4. Anomaly 4 is a small high amplitude response visible in slices 1-5 (0-22.1ns/0-0.77m). It is roughly 1m in diameter and lies about 5m to the east of the centre of Grid 6.

5. Anomaly 5 is a second group of alternating higher and lower amplitude responses, marked by solid lines in Figure 10.82. These appear from slice 1-2 (0-10.14ns/0-0.14m). They are again quite widely spaced with about 4m between each higher amplitude line. They run on the same wnw-ese alignment as anomaly 1 and appear to respect its dimensions. They cover most of Grid 2 and the upper 2/3 of Grid 1, with extensions into the northwest quadrant of Grid 3.

6. Anomaly 6 covers almost the whole survey area, but is more visible in some areas than others. There is a strong set of linear responses running sw/ne across the whole survey area, marked by broken lines on Figure 10.82. Importantly, these lines underlie the other anomalies noted (except 4), appearing in slices 5-7 (15.95-30.08ns/0.56-1.05m). They are much more closely spaced than anomalies 3 and 5, with only about a 1m interval between the lines.

Interpretation

RM15 resistivity survey

Probe separation A (0.25m) - Figure 10.98

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. There do not appear to be any archaeologically significant anomalies.

Probe separation B (0.5m) - Figure 10.99

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. There do not appear to be any archaeologically significant anomalies.

Probe separation C (0.75m) - Figure 10.100

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. There do not appear to be any archaeologically significant anomalies.

Probe separation D (1.0m) - Figure 10.101

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. The extension of this drying north and east towards the former excavations points to general dewatering of the upper layers of the peat. This appears to be being mitigated to some extent by leaving the grass uncut at the edges of the field (the eastern, northern and southern sides of Grids 5 and 6). There do not appear to be any archaeologically significant anomalies.

Probe separation E (1.25m) - Figure 10.102

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. The extension of this drying north and west towards the former excavations points to general dewatering of the upper layers of the peat. This appears to be being mitigated to some extent by leaving the grass uncut at the edges of the field (the eastern, northern and southern sides of Grids 5 and 6). There do not appear to be any archaeologically significant anomalies.

Probe separation F (1.5m) - Figure 10.103

The wide range in the raw data is largely due to the very dry conditions at the immediate ground surface, with numerous deep cracks in the topsoil, some up to 5cm across and over 10cm deep. The zoning in the data seems likely to be due to general

changes in the soil moisture levels, perhaps associated with drainage into the dyke immediately to the south of the survey. The extension of this drying north and west towards the former excavations points to general dewatering of the upper layers of the peat. This appears to be being mitigated to some extent by leaving the grass uncut at the edges of the field (the eastern, northern and southern sides of Grids 5&6). There do not appear to be any archaeologically significant anomalies.

DualGrad 601 gradiometry survey- Figure 10.104

The gradiometry anomalies make most sense when considered alongside the 250 MHz radar data. The spikes in Grids 1 and 3 seem to be associated with the remains of a ripped out field boundary, which is still marked on the plans held by the Trust (in blue on the maps). It is likely this is ferrous material associated with fencing or being cleared into the fence/hedge line from a cultivated field. In this data, the linear alternating trend seems to respect this boundary running in Grids 1 and 3, though it seems to be slightly off 90 degrees to it. This is interpreted as a either a ploughing trend, or the remains of hand-cut peat works. This trend and the linear trend noted as anomaly 6 match, though the radar seems to have picked up a more extensive response. The radar data shows this system continues under and beyond the field boundaries making this earlier than the field system still reflected in the Ordnance Survey and Trust mapping of the area. The concentrations of spikes along these lines could be a reflection on manuring practices with ferrous or otherwise enhanced material being incorporated along the lines of ploughing, or material finding its way into exposed peat cuttings.

EM38 survey
Vertical quadrature phase response- Figure 10.105
As could be expected, the quadrature phase results match well with the resistivity survey, being a measure of soil conductivity. The less conductive patch seems to be a reflection of dewatering in the southern part of the field, with a 'halo' of more protected soils adjacent to the un-cut grasses around the eastern end of the survey area. The EM is most sensitive at a depth of about 0.3 to 0.5m so the results from the wider probe spacings do show slightly different results.

Vertical inphase response- Figure 10.106

The inphase results are slightly surprising, given the presence of ferrous spikes in the area of the old field boundary in Grids 1 and 3. This shows up as reduced MS, but this could be due to the presence of different vegetation along this line (brambles, nettles and the odd remnant of hawthorn hedge), lifting the instrument slightly and thus diluting the response from the soils. The increases are relative to a background, and are very slight, but could reflect enhanced material being washed down from the causeway, which runs along the northern edge of the survey area.

GPR 500 MHz survey- Figure 10.107

As discussed in the results section, each anomaly (or group of them) has been given a number. They are discussed below, by number.

1. Anomaly 1 is a shallow but very high energy response, appearing in the top 0.3m of the data, with disturbances visible in the data down to the base of the recorded responses. It is possible this is 'ringing' from the high energy response higher up in the profile. It very precisely coincides with an old field boundary located in the OS line data and Trusts' own mapping. The boundary has been removed at some time in the recent past, leaving an area of scrubby vegetation that is markedly different from the grasses covering the rest of the survey area. It is likely that the radar response is a mixture of a strong surface reflection from this trampled vegetation, and the different character of the soil under what clearly used to be a hawthorn hedge.

2. Anomaly 2 also coincides with a field boundary in the mapping, but there is nothing left of this land division visible at the surface. It is likely the radar is reflecting from either disturbed or compacted ground along the old fence/ hedge line, or buried remnants of this.

3. Regular alternating bands like anomaly 3 have been shown to represent ploughing trends, with soil being alternately compressed and loosened in the process of ridge and furrow ploughing. Even when the surface has been levelled off, these differences in soil compaction at depth can be detected by a variety of geophysical means. Interestingly, this was not picked up by the resistivity survey, suggesting that the different compactions of the soil are equally dry.

4. Anomaly 4 is a strong reflection, only 1m across (though it is possible this size is due to the resolution of the survey, and the feature is smaller or larger by up to 0.5m). It appears from 0-0.7m. An archaeological origin seems unlikely; this area of the survey was riddled with cracks and fissures. It could be a strong reflection from one of these or an animal burrow of some sort.

5. Anomaly 5 coincides with a vegetation change from the managed, but un-mown grasses over much of the survey area, and the regularly cut grass covering the old causeway. The change in amplitude could be due to this and moisture differences as a result, or it could be due to the creep of soil material down the slope of the causeway.

6. Anomaly 6 occurs under anomaly 2, the old field boundary, and given its depth and dimensions is likely to be root material or an animal burrow associated with that field boundary.

7. Anomaly 7 occurs under anomaly 2, the old field boundary, and given its depth and dimensions is likely to be root material or an animal burrow associated with that field boundary.

8. Regular alternating bands like anomaly 8 have been shown to represent ploughing trends, with soil being alternately compressed and loosened in the process of ridge and furrow ploughing. Even when the surface has been levelled off, these differences in soil compaction at depth can be detected by a variety of geophysical means. Interestingly, this was not picked up by the resistivity survey, suggesting that the different compactions of the soil are equally dry. They are on a different alignment to those in anomaly 3, and are possibly a very faint response to the same linear anomalies being picked up in the gradiometer data and as anomaly 6 in the 250MHz GPR data, discussed below, though they appear to be at a very different depth- 0.1m rather than between 0.5 and 1m. It is possible therefore that there are two superimposed sets of ploughing trends on roughly the same alignments, but from different periods of the sites history.

9. Anomaly 9 only appears in the very top of the response, and while it does neatly line up with the line of the post alignment and some of the features uncovered at depth by excavations, it is in fact an artefact of the survey method. The GPR survey was conducted around the other survey work on the site, and as GPR is surveyed in long runs rather than the 20m Grids of the

other techniques, the long grass in the field became trampled flat along the midline of the Grids as strings were moved, tapes re-set etc. This anomaly is almost certainly a reflection of this, rather than any archaeology.

GPR 250 MHz survey- Figure 10.108

As discussed in the results section, each anomaly (or group of them) has been given a number. They are discussed below, by number.

1. As discussed above, anomaly 1 appears to represent an old field boundary, probably in a combination of reflecting the change in vegetation in this area and differing ground conditions below the hedgerow than in the field it defined. The noise visible in the 500 MHz survey to about 1m does not show in this data, making it likely that this is 'ringing' rather than an extension of the anomaly to that depth.
2. Anomaly 2, again, as discussed above, seems to be related to a less substantial field boundary from the same system and time as anomaly 1.
3. Anomaly 3 is interpreted as reflections from a ploughing trend, and likely to be related to the field boundaries represented by anomalies 1 & 2. It appears to be the same anomaly as anomaly 3 in the 500 MHz data, though different areas are showing with a greater degree of clarity.
4. Anomaly 4 is in the same location as the anomaly 4 in the 500 MHz radar data, and is interpreted as either being a deep crack in the peat or some sort of animal burrow.
5. The group of linear anomalies labelled anomaly 5 does not appear in the 500 MHz data but occurs at the same depth and is of a similar character to (though on a different alignment) anomaly 3 in both the 250 MHz and 500 MHz GPR data. It is interpreted as representing a ploughing trend associated with the field boundaries noted as anomalies 2&3.
6. Anomaly 6 covers most of the survey area and is possibly worthy of the most discussion. Further research both on site and in the literature needs to be done to fully understand this response. It appears to be being caused by the same archaeological feature responsible for anomaly 8 in the 500 MHz GPR data and the linear trend noted in the gradiometer data (see above). It lies at 0.5-1m depth, and conclusively underlies the field system suggested by the

gradiometer, EM and radar data. The trend is on a very different alignment to this system, and the gaps between features are much smaller; about 1m intervals. This is very unlike medieval ploughing which typically has a greater interval between furrows. A possible candidate is a prehistoric type of cultivation known as cord rig (Darvill 2002, 101), though this would be highly unusual, as this type of prehistoric cultivation is only known in the Scottish Borders and northern England, and is an upland phenomena. The other issue with this interpretation is that previous research (Pryor 1992b; 2001) has shown that this part of the fen was particularly wet, right through to the Roman period (hence the causeway); thus crop cultivation seems unlikely prior to the fens being drained at the end of the middle ages. However, there is evidence of a similar ploughzone from prehistoric levels further up in the Nene valley (French 2003a, 107). The other, possibility is that these are old peat works, hand cut by shovels which tend to be about 1m across. They are very regular, with very even spacing between the rows. It cannot be discounted that they might be modern or at least post medieval and some sort of machine cultivation, but this would mean a very drastic change in the layout of the landscape and a very short time for the overlying features to have developed. It is also uncertain at this stage where the overlying 0.5m (approximately) of soil came from, unless this is a reflection from the base of a very truncated system (which seems unlikely). It is also unclear what prevented more of this system being detected at this depth by the 500 MHz GPR survey, as it lies within the active depth of that antenna. Anomaly 8 in the 500 MHz data appears to be on the same alignment but at a very different depth, visible about 0.1m down in the soil profile. A search for comparable features in other surveys from the area is needed, and possible further processing of both sets of GPR data to see what else can be learned.

10.2.5 Case-study specific conclusions

Referring back to the objectives in turn, we can consider the survey successful even though from the present results we have not been able to identify any prehistoric timber remains in the surveys. The aims were as follows:

1. To see if any anomalies relating to the post alignment could be detected, and if so, what they could tell us about its extent or preservation.

The surveys have clearly demonstrated that the techniques employed are not capable of detecting the waterlogged wooden remains of the post alignment. It seems most likely that this is due to both the depth of the overburden on this site, and its makeup, which includes layers of clayey alluvium, which will dissipate the radar energy rapidly (French 2003a). It is still possible that very low frequency radar (100MHz and below) could penetrate this layer and get signal returns from below it, from both the wood and the underlying landform. For similar reasons we have not been able to establish the form of the fen basin, or detect any offshoots or further timber structures.

2. To evaluate the responses of all four geophysical techniques to this particular peatland environment.

Though no prehistoric timbers were detected, all four of the survey techniques produced responses to the soil conditions on the site that are useful archaeologically. In the resistivity, though no archaeological features were detected, the pattern of wetter and drier soils and their apparent association with the grass cutting regime has implications for the management of the site. The gradiometer survey revealed some information about prior uses of the site, showing ploughing trends and field boundaries, some of which might be prehistoric. The GPR data, in particular the 250 MHz data also showed similar information, but importantly allowed it to be placed in a relative sequence based on the depths of the anomalies. The EM data complemented the resistivity, radar and magnetometry data acting as a useful check on the results. This aspect of the survey then was very successful, revealing both the limitations (the prehistoric wood is likely too deep and possibly to homogenous) of the equipment and its great potential for more shallowly buried targets in these soils. As with the Area 1 surveys, there seems to be great potential for some of the techniques to be used in management strategies, rather than for detecting the archaeology.

10.3 Evaluation of techniques

The geophysical surveys of this landscape did not locate any prehistoric archaeological features at all, and were not able to answer to the aims of the study; to locate and assess the prehistoric timbers on the site. What they have done, is show a variety of invisible landscape features from later periods that add to our knowledge of the site after the fens were drained. There also seem to be strong indications that

geophysical techniques, particularly electrical ones might have some role to play in monitoring and managing the moisture levels in the soil.

10.4 Ground-truthing work

The ground-truthing work at Flag Fen was limited by comparison with the investigations carried out at Yellowmead Down and at the Canada Farm area of the Sweet Track. A targeted series of gouge-auger cores was conducted to test specific geophysical anomalies or areas of interest. The ground there was simply too dry to hand core using the Russian auger employed in Somerset, so the investigation was limited to logging the subsurface horizons in each core, giving a description and Munsell colour. Where deposits of interest were encountered, small samples were able to be taken for further testing in the laboratory of moisture content, LOI and MS, but the quantities of each were limited.

Figure 10.109 shows the core locations and Table 13 below shows the justification for each core.

Table 12: Cores at Flag Fen

Core Number	Rationale
1	To investigate magnetic enhancement at edge of the Roman road
2	To establish the 'normal' soil profile on this part of the site and establish the water-table height
3	To investigate high resistance/ GPR reflection anomaly possibly associated with a tree- drying or more Roman road?
4	To establish the 'normal' soil profile on this part of the site and establish the water-table height
5	A second core through the high resistance feature was planned but abandoned due to severe difficulties coring the anomaly at location 3.
6	To examine soil profile and also hopefully catch both cultivated soils shown in GPR survey and Gradiometer survey
7	To establish the 'normal' soil profile on this part of the site and establish the water-table height

10.4.1 Coring and physical analyses

Field methods and sample storage

The cores were taken on 10 October 2009, on a dry and clear day following a period of wet weather. The planned core locations had been planned based on the geophysical interpretations in the GIS and then loaded into a hand-held GPS unit (with roughly 1m accuracy). Each core was located and a further co-ordinate taken

with the GPS unit to recorded the actual location the core was taken as some had to be moved because of local circumstances; vegetation etc.

Cores were taken using a hand-operated gouge-auger. Coring conditions were much more difficult than had originally been anticipated, so Core 1 and Core 7 have a second attempted bore adjacent to the original one. The sediments were described and recorded, along with a Munsell colour for each horizon identified. The resulting characterisations are shown in Figure 10.110. Core 5 was abandoned due to the difficulties encountered in obtaining Cores 3 and 4 in the same part of the site. In many cases it was not possible to achieve the desired depth, or reach waterlogged deposits due to the presence of a compacted clayey layer. In Core 7, this layer was breached using a corkscrew auger to get through it before returning to the gouge to allow better characterisation of the sediments.

Horizons that seemed unusual or related to the geophysical response were sampled into airtight pots or zip lock bags, and were refrigerated as soon as possible on return to the University below 5°C, until they were further examined to try to limit oxidation and bacterial activity.

The long hand descriptions of the cores follow, transcribed from notes made in the field.

Core 1/ 1A
The first attempt at coring at location 1 had to be abandoned as the sediment was too dry and compact to hand auger. The planned location turned out to be too close to the spread of material from both the Roman causeway and the modern footpath which overlies it at this point. Just 15cm of topsoil was recovered and sampled in 3 5cm sections for laboratory testing. It consisted of very poorly structured reddish sandy gravel with a lot of small stones without a great deal of humic material or obvious plant remains. The Munsell colour was 5.7 YR 5/8 'Strong Brown'.

A second core was attempted (Core 1A) about 0.5m north of the first attempt. This core was pursued to a depth of 1m only, as it was intended to investigate shallow geophysical anomalies associated with the Roman causeway. The first 60cm of the

core was void, but appeared to be a less structured and drier continuation of what was recovered from 60-80cm. This, like what was retrieved in core 1 was a poorly structured sandy/gravelly deposit with lots of rounded small stones, reddish in colour, without much humic material. It was very compact and hard to core through, but once disturbed had little structure or cohesion. The Munsell colour was 5.7 YR 5/8 'Strong Brown'.

There was a sharp boundary at 80cm to a silty, well humified layer with grey brown mottling and black flecks. There seemed to be some organic fragments. This layer continued to 96cm deep. The Munsell colour was 10YR 2/1 'Black'.

There was another abrupt boundary at 96cm to a deposit similar to the upper layer, but more compact and sandy with less stones, and slightly more humic material. This was Munsell colour 5.7YR 5/8 'Strong Brown' again.

A sample of each horizon was taken for laboratory testing.

Core 2
It was only possible to core to 48cm in this location, due to the presence of a compact silty/clayey layer.

The first 20cm of the core were void, probably due to the dry surface conditions. Some loose, sandy material was recovered with very small stones and some irregular aggregated soil peds. Material was recovered from 20-48cm. The deposit had no clear horizons, though there was a gradual change over depth, starting out much like the material loosely recovered from the voided section, but becoming more silty and clayey with depth, becoming very compact with dark flecks and some sandy particles but mostly a compact silt/clay deposit. There were orangey flecks and possibly some burnt particles, that seemed to be burned material incorporated with the soil, rather than burned soil. The Munsell colour was 10 YR 4/3 'Brown'.
A sample from 34-48cm was taken for laboratory testing.

Core 3

This core was physically very difficult to take, but was eventually pursued to a depth of 90cm. This had been anticipated as it was through a high resistance/GPR reflection anomaly, and the core was to establish if this was an offshoot of the Roman causeway.

The upper part of the core to 25cm was void, though it seemed to be a drier, less structured continuation of the horizon from recovered from 25-37cm. This layer had very many small to medium sized stones and sandy material, with very little humic matter. It was sandy coloured as well, with a Munsell colour of 10YR 4/4 'Dark Yellowish Brown' recorded.

There was a gradual transition over about 23cm to 50cm with slightly more humic material, more clay and less stones and sand, though where there were stones, they were larger.

There was a change at about 50cm; no more stones are seen below this point. The deposit becomes very clayey and fines further downwards. From about 68cm there are orangey flecks and towards 90cm there start to be dark brown and black flecks. The colour from 23cm to 90cm was fairly uniform and was recorded as Munsell colour 10YR 4/3 'Brown'.

Samples were taken for laboratory testing from 25-37cm, 37-50cm, 50-70cm and 70-90cm.

Core 4

It was impossible to core below 45cm at this location due to the compact silty clay layer mentioned above.

The first 17cm of this core were void probably due to the dry nature of the soil. The voided material appeared to be similar to that recovered from 17-27cm down, which was a loosely compacted dry soil with some small stones and rootlets. It was dark in colour, with none of the red/yellow tinting noted at the surface in cores 1 and 3, and not particularly sandy. The Munsell colour recorded was 10YR 3/2 'Very Dark Greyish Brown'.

From 27cm to 45cm, the maximum depth we could obtain, there was a rapid change to a much more compact clayey layer with drier zones in it which had light greenish yellow mottles (specifically at 35-37cm, Munsell colour 5Y 6/6 'Olive Yellow'). The soil became stickier with depth, with red flecks visible from 39cm. It was very compact and dry towards the base with very infrequent small stones and some black flecks, again seeming to represent burnt matter that had become incorporated in the soil matrix rather than burned soil. The Munsell colour remained the same as the upper deposit, with the changes being in texture and structure rather than colour.

A sample of the core at 40-45cm was recovered for laboratory testing.

Core 6

Core 6 was pursued to a depth of 1m, but this took two attempts and there was a voided zone in the middle of the core.

The core was void to 19cm, with some loosely compacted sub angular soil peds recovered. Even where the soil had some structure there was a lot of airspace. There was quite an abrupt boundary at 19cm with a horizon that extended to the end of the first attempt; 40cm. This was a humic, almost greasy well developed and compact soil with lots of black flecks and possible fragments of burned clay and bright orange flecks. There were very few small stones. The Munsell colour recorded was 10 YR 3/2 'Very Dark Greyish Brown'. In the second 'bite' of the core, the top 20cm were voided (to 60cm from surface) but the deposit lost seems to have been the same as that from 19-40cm.

From 60-78 the deposit seems to have been largely similar but less compact; this is perhaps why it voided in the 40-60cm range. The colour was the same, but the bottom 8cm (70-78cm) were noticeably more compacted than the upper deposit.

At 78-80cm there was a sharp transition zone to a more silty deposit that seemed wetter but was not saturated. It was a mixture of the greyish brown colour noted previously and tending towards black, and getting blacker with depth, in uneven

mottles. From about 96cm to the end of the core at 100cm the soil has become black, humic, wet silty material with a Munsell colour value of 10 YR 2/1 'Black'.

This core was sampled for laboratory testing at 17-24cm, 24-29cm, 29-34cm, 24-39cm and 96-100cm.

Core 7/ 7A
Core 7 was the deepest collected, and this was only possible because a screw auger was used to remove the silty/clayey layer that had caused problems in the other cores. As such, some of the sequence is less well described, as this method does not recover intact sequences and tends to break up soils and mix them slightly.

The fist part of the core, to a depth of 30cm was void. As the corer was pushed in, several air pockets were noticed, so it is possible that the soil recorded from 30-40cm is compacted from higher up in the profile. From 30-40cm a mixture of small hard aggregated peds and rootlets was recovered with a few small stones. Some of the peds showed orange flecks and black flecks. The orange flecks had a Munsell value of 10 YR 6/8 'Brownish Yellow'. The colour of the main soil matrix was 10 YR 4/2 'Dark Greyish Brown'.

From 40-52cm the soil had larger peds and generally more material in the spaces between them. It was generally more coherent, but still had lots of rootlets and black and orangey flecks. Where peds were cut, they appeared clayey (?) and glossy. The colour was 10 YR 3/2 'Very Dark Greyish Brown'.

From 52-60cm, where it stopped being possible to gouge auger, the deposit had less obvious peds and pore spaces. The colours looked redder and the soil felt wetter. There were still abundant rootlets. The soil seemed less clayey with depth. The colour was Munsell shade 10 YR 2/2 'Very Dark Brown'.

This zone seemed very hard to core through so the screw auger was used to try to get through this tough zone into hopefully wetter and softer deposits below. 60-100cm was removed with this tool, and what was recovered was a mixture of dark peaty soil and dark grey/brown very tough silty material; the method made it very hard to

distinguish horizons or how many interleavings of this material was present. When the sediment noticeably softened the gouge auger was re-employed to get a better picture of the sediments.

From 100-108cm was void/ contaminated with the previous mixed material from the screw auger.

Here, 108-150cm was the maximum depth achieved. This soil was wet, silty, very well humified and dark. There were no roots or identifiable organic material present, but there were lenses of crystalline material that started appearing as the core began to dry out during the inspection. They seemed to be mineral rather than mycelium; possibly gypsum or another mineral salt. There was no apparent fibre or structure to the sediment. When the core was cut, it was apparent there were mottles and inclusions of greenish grey matter within the darker matrix (possibly the remains of a waterlogged reed bed, French 2010), and there were woody remains at 120, 127 and 135-138cm, with the latter being a pronounced woody patch. This overlay a pronounced blue/grey silty deposit with sandy flecks and a sulphurous smell. This greenish yellow sandy material was also at the very base of the core, at 150cm and is possibly what prevented further coring. The overall colour of the soil in this horizon was not given a Munsell number, but the greenish mottling was described as 5GY 5/1 'Greenish Grey'.

Due to the mixing problems in the middle of this core, it was selectively sampled for laboratory testing as follows; 5 x 5cm sections from 40-60cm and 7 x 5cm sections from 110-145cm.

The air spaces encountered, and some of the voiding in the cores may be due to drying cracks in the peaty alluvium (French, 2010).

Laboratory methods

Two sets of measurements were made on the 29 sub-samples taken from the cores. The depth range of the cores varies; some sequences of interest were sampled in 5 cm sections, whilst others were simple split at observed interfaces and as such might sample a range of up to 30cm of core, but all judged to be the same soil horizon. The

moisture content and loss on ignition were calculated using established methods, but there was not enough sampled material for repeat measurements, so some margin of error must be accepted for these results.

Prior to the heating and ashing involved in LOI testing, the samples were also measured for magnetic susceptibility. The samples were not dried, sieved or otherwise prepared prior to testing, apart from breaking them up to allow them to homogenously fill the sample pots.

The same methods for both tests were followed as described in section 9.4. and Figures 10.111 to 10.113 were generated from the results, following the same calculation methods as referred to in section 9.4.

Moisture content and LOI tests

These two measurements are often related, as higher organic contents allow soils to store more water. The results indicate that many of the sediments cored through cannot technically be described as peat soils (over 40% organic and persisting for several decimetres (Burton & Hodgson 1987) they are underlain by extensive peat deposits and the environment is certainly 'peatland'. Moisture contents generally reflected the presence of greater amounts of organic material and in two cores, 6 and 7; peat was encountered at depths of 96cm and 110-130cm respectively. The other deposits showed a generally low organic content, under 20% for the most part, with correspondingly low moisture contents.

Magnetic susceptibility

As stated above, the samples were not dried or sieved prior to testing, but the measurements were made following the method outlined in Section 9.4 and the results are presented as Figure 10.104.

The MS results varied greatly on this site, with values between +195.3 to -0.5 volume specific MS. The variations were strong within cores, not just between coring locations, with a range of values in core 7/7A from +130.2 down to -0.5. In general, the higher values correspond well with the clayey/ silty layers noted in the core logs, and the very low numbers with the peaty horizons. Where the low frequency

susceptibility values exceed 10 (Dearing 1999, 18), as is the case for many of these measurements, it is possible to talk about percentage frequency dependence, and examine the differences between the high and low frequency response, as an indirect observation of the grain sizes of the magnetic minerals. A frequency dependence of more than 7% has been linked with the presence of higher amounts of superparamagnetic particles, which have associations with human habitation and industry (Dewar *et al.* 2002; Peters *et al.* 2002). Some of the deposits at Flag Fen showed this characteristic: from 60cm to 96cm in Core 1A, 34cm to 48cm in Core 2, and 45cm to 60cm in Core 7, with values between 8% and 10%. Some other samples showed high frequency dependence, but also have low low-frequency MS values (between 10 and 25), meaning the frequency dependence calculation was very prone to error (Dearing 1999, 18), so these samples have not been considered further. There is also a likelihood that iron deposited during the humification and drying of the peats is skewing these results; as noted at the Sweet Track iron can be deposited at the extremes of a variable water table.

Discussion

Firstly, the observations of the soil horizons that show the inclusion of burned material and burned clay, coupled with the MS measurements and frequency dependence tests, strongly suggest buried soils with strong anthropogenic influences on the site, particularly in Area 2, though caution needs to be exercised due to the potential of iron redeposition skewing the results.

Cores 1 and 3 were specifically aimed at understanding the sediments immediately adjacent to the Roman causeway and some interesting geophysical anomalies it appeared to be responsible for. Core 1 and core 3 both had very different upper portions to cores 2 and 4, which were deliberate 'off anomaly' cores. Furthermore, their make-up was similar, suggesting that the large geophysical anomaly in Area 1 that showed in the resistivity, conductivity, and GPR surveys is indeed related to the causeway; perhaps an offshoot or material that has been dragged away from the road in subsequent ploughing. Core 1 suggests that the MS anomalies in this area are a result of a build up of anthropogenically influenced soils in a ploughing headland created by the presence of the causeway; during our involvement with the site a service trench was dug near to where Core 1 was taken which showed that later

ploughing had been obstructed by the causeway, and so it had formed a natural break in the landscape as the plough had to turn as it came up to it (pers. com. Webber 2008).

All of the cores in this area showed a compacted silty clayey layer. This layer was also present in area 2, but it occurred at different depths, and had slightly different composition depending on where on the site you were. These variations make it much harder to argue for a consistent 'master sequence' of sediments on the site; there seem to be highly localised changes happening. However, there does overall appear to be a layer of silty/clayey material with human influences, showing high MS values and frequency dependencies, and flecks of black and reddish material which may be products of burning. This appears to overlie the wetter deposits on the site, and furthermore, be contemporary, or prior to the Roman causeway sequence at Area One.

Unfortunately, the depth range 70-90cm which produced the spectacular diagonal linear anomalies in the GPR data (Figures 10.84 and 10.85) was not directly sampled, but samples from above that range carry the high MS/ high frequency dependence signature. It is also possible that we have overestimated the GPR propagation speed in these sediments, when making the depth estimates, as it was initially assumed that the subsurface would be quite wet. A revision to these depth estimates would place the linear anomalies well into the sampled area that showed the strong anthropogenic characteristics.

Cores 6 and 7 were the only cores that adequately explored what underlies this layer on the site, and seemed to show it overlies a much wetter poorly structured peaty/organic deposit. One interpretation of the combined geophysical and coring evidence is that there is a buried landscape of late prehistoric/ Romano-British arable fields which were created on 'improved' peat; a plaggen-type soil, where other material such as ash has been incorporated to give the soil structure. This would have had, from the GPR data a narrow, regular ridge and furrow appearance. This type of ploughing (though not plaggen-type enhancement) has been suggested for nearby soils from further up the Nene valley (French 2003a, 138). It is also possible that this a humified amorphous iron-rich peat horizon, or a dried out silty/clay surface with amorphous iron and salts, or a mixture of the two (French 2010).

The coring has also demonstrated that the immediate surface deposits on this site are very dry, and whilst there does seem to be wetter material surviving below this desiccated zone, there are important conservation issues to address. While it is hoped much of the platform is protected under the artificial mere, there is a wealth of archaeology on the site from earlier and later periods that is not, and may be at severe risk of drying out (Pryor 2005).

Overall, it is important to note that the sediment sequence is complex, and appears to have been under human influence for all of the accumulation period; none of the sediments encountered were 'natural' soils. This complexity combined with the drying and larger amounts of clay than expected are likely to be the main obstacles to reliably surveying the prehistoric timbers in the deeper, waterlogged sediments.

10.5 Conclusions

The landscape at Flag Fen is very complex, with all of the sediments encountered in the coring exercise apparently anthropogenically influenced. The coring work has allowed the confirmation of a number of important conclusions from the geophysical surveys.

In Area 1, the surveys have located a probable offshoot of the Roman causeway, and demonstrated the causeway remained an important landscape feature into the medieval period, influencing landscape divisions and agricultural practice.

In Area 2, a prehistoric (probably late Iron-Age or Romano-British) arable landscape with an unusual narrow ridge and furrow pattern was detected in the GPR and gradiometer surveys. There is a later agricultural landscape visible in the geophysical surveys as well, lying above this one.

The detection of these landscape-scale features challenge future research to look at the archaeology of Flag Fen beyond the Bronze Age landscape, and at a scale in between those that have been examined to date. There has been excellent, highly detailed work on the timber Bronze Age archaeology, and equally excellent and detailed work at a much larger scale, looking at the development of the landscape and hydrological systems in the area. Geophysical survey, backed up by selective coring and

geoarchaeological study has been shown to be a useful tool to examine what people were doing in that wider landscape. Further research and persistence may yet allow the detection and mapping of the important timbers on the site, but these surveys have revealed a rich set of landscapes overlying these features that is due some consideration as well. In particular, the unusual arable system in Area 2 has been guessed at before from geoarchaeological work in the area. Little is known about this type of agriculture; in the past it had been assumed this type of 'cord rig' ploughing was limited to the north of the British Isles (Darvill 2002). This interpretation needs to be approached with caution as there are alternative interpretations for the characteristics and formation of the soil horizon, and the similar ploughing noted elsewhere in the Nene Valley was on ash and organic matter- enhanced brown earths on terrace gravels (French 2010).

These surveys also demonstrate the potential for geophysical survey as a conservation tool, to assist in the active management of these landscapes; both for exploring the archaeological resource, and assessing the preservation environment. Further research is needed to explore the possibility of using EM survey as a rapid assessment of desiccation, and this should be a priority, as if the environmental characteristics that preserve the archaeology are damaged, we won't have anything to excavate or survey to answer the other questions.

Chapter 11: Dartmoor, Devon

Two case study sites were selected in this important upland peat environment with the assistance of the Dartmoor National Park Authority (DNPA). They were able to suggest accessible sites where there were archaeologically interesting questions that geophysical survey might usefully be employed to answer, on sites where there was already known and documented archaeology. Both sites are close to each other, on western Dartmoor (Figure 11.1).

11.1 Yellowmead Down

11.1.1 Site background

As it presently stands, the monument known as Yellowmead Down Multiple Stone circles consists of:

> *…four stone circles around a cairn and with a stone row extending away from the south west side is situated on the south west facing slope of Yellowmead Down. The four circles are not concentric and there is a further arc of seven stones up to 0.4m in height on the west side which may be the remains of a fifth circle. The innermost circle has 22 stones up to 0.9m in height; it surrounds a cairn 4m in diameter and 0.2m in height. The outer rings have 32, 27 and 30 stones respectively, the inner two being only up to 0.25m in height and all having their largest stones around the south side. The maximum diameter of the outer circle is some 30m. The remains of a double stone alignment extend some 10m from the south west side; there are three stones in the south row and a similar number in the north row, although more were recorded in 1922. The stones of the alignments are up to 0.3m in height and on average 2m apart. The alignment avenue is approximately 1m in width.*

 (National Monuments Record 1993b, record 10748)

There is also a small cairn upslope of the stone circles which was also investigated:

> *This cairn lies some 50m north east of Yellowmead stone circles on the south west facing slopes of Yellowmead Down. It consists of an earth and stone*

mound 4m in diameter and up to 0.3m in height with four stones of a retaining
kerb on its west and south sides.

(National Monuments Record 1993a, record 10749)

The stone circles were re-erected in 1922. It is not clear if the innermost circle surrounded a cairn or was the retaining wall of a cairn. The nature and extent of the stone rows has also been debated (Devon County Council 1992, record 3338).

Bronze Age

Dated by morphology and typology only, at some point Early to Middle Bronze Age (Early 2nd millennium calBC) the stone circles were built (arguably as either a set of concentric rings, as at Glasscombe or as some sort of ringed cairn, as at Corringdon Ball or Carnedd Hengwm Gwyn (Devon County Council 1992, record 3338). Butler (1994, 74) draws comparisons to Shovel Down and Corringdon Ball. There are contested multiple stone rows running downslope of the circles, though it has also been suggested they may instead be the remains of a fifth circular setting of stones (National Monuments Record 1993b, 10748). Up to 9 have been proposed, and it is suggested that the apparently 'fan-like' construction is a relic of later restoration, not the original alignment.

The cairn upslope of the monument has also been assigned a Bronze Age date on typological grounds.

In the statement that accompanies the scheduling record, the author is keen to emphasise the importance of the archaeology on Dartmoor as a whole landscape, preserving a nationally important range of settlements, land divisions and ritual and funerary sites. The unique nature of this particular site is noted, adding that it illustrates the diversity of the archaeology in this particular part of the moor (National Monuments Record 1993b, record 10748).

Medieval/ Post Medieval

At some point in the Medieval period, or later, once Dartmoor was being brought back into use, a leat was constructed on the site to divert the flow of water into sheet

mining operations. This appears to connect tin streaming scars (see Figure 11.2) which in turn relate to the remains of a blowing house. This dates to the Medieval period or later and so possibly dates the leat by association.

The leat did not disturb any of the circles but, if the stone rows do exist, it cuts through the line of them. The leat passes close enough to the circle that is seems to make sense for it to be in some way 'respecting' a visible landscape feature, indicating that there was some monument visible at the surface at the time of its construction. There are also some pronounced hollows on the site, different to the normal topography, (see Figure 11.3) which might be related to tin prospection or treasure seeking by tinners.

Reconstruction

In 1921 the stones visible on the surface of the site were re-erected 'where they lay' by Rev Hugh Breton, and the restoration was declared to be 'very faithfully done' by R H Worth (Butler 1994, 74). There is some dispute in the literature about the existence of several (up to nine are suggested) stone rows running downslope from the monument (Brailsford 1938, 447). Some have apparently been reconstructed in a fan-like arrangement (Butler 1994, 76) thought to be incorrect.

Current land use

The land is currently common grazing, with sheep, ponies and cattle all using the landscape. There are also well established footpaths leading to the monument. The site has suffered with some problems of erosion, especially around the larger uprights as they are used as scratching posts by the fauna of Dartmoor. Some of these larger stones have had to be repaired (with a resin), possibly as a result of the same animal action.

The soils are thin peat soils over weathered Dartmoor Granite.

11.1.2 Survey aims

This site provided a number of interesting and challenging questions for a geophysical survey to answer. These were agreed in consultation with Jane Marchand from the Dartmoor National Parks' archaeology service. The agreed aims were as follows:

- To establish the fidelity of the antiquarian 'reconstruction' of the monument by looking for other stone settings or buried features
- To establish if there was a previous monument on the site, and if so shed some light on the possible sequence of construction
- To prospect for features now not visible above the blanket peat, and examine the original landform prior to peat growth.
- To examine the relationship between the stone circle and the associated cairn.
- To examine the 'stone rows' on the site and see if any continuation of them can be detected and planned.

11.1.3 Methods and instrument settings

Fieldwork was carried out over three periods; 18-20 January, 25-27 January 14-17 and 30 April 2008. The conditions were highly varied, but mostly wet, with surface water continually on much of the site. The resistivity survey was carried out on a dry day, following a drier period but the ground was still damp to the touch. During the second period in January there was an overnight frost but the ground was not frozen. The leat was dry at the time of the resistivity survey, but full of water for much of the other work, hence the small gap in the GPR survey.

Ten grids (two parallel rows of five) were established on site, laid out along a base line running from the centre of the stone circles to the centre of the cairn. The grids were laid out by hand from this base line (as there were no further grids to offset), then surveyed in by dGPS. The base line was positioned so that the stone circles were effectively quadranted by four of the grids (see Figure 11.3).

Table 13: Instruments used in the surveys at Yellowmead Down

Survey type	Instrument	Accessories/notes
Resistivity	Geoscan Research RM15	0.5m twin probe configuration.
Magnetometry (gradiometer)	Geoscan Research FM36	Automatic trigger used for survey
Electro-Magnetic	Geonics EM38B	Vertical dipole orientation. Both inphase and quadrature components of the response logged.
Ground Penetrating Radar	Mala RAMAC GPR	500 MHz antennae employed, 100 MHz survey wheel used to measure distances.

Table 14: Sampling intervals and instrument settings used at Yellowmead Down

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
RM15	0.5m	0.5m	Zig-Zag	0.5 ohm resolution
FM36	0.5m	0.5m	Parallel	0.1 nT resolution
Mala RAMAC 500 MHz	0.5m	0.02m	Zig-Zag	Depth setting: Shallow: 63.4ns time window. 512 samples. Presumed velocity of 0.08m/ns
EM38B	1m	1m	Zig-Zag	Both inphase and quadrature responses logged.

Once collected and downloaded the data was processed in GEOPLOT and GPR-SLICE as appropriate. See Appendix A for a detailed log of the corrections and enhancements applied.

11.1.4 Results and interpretations

For the data plots, see Figures 11.4 to 11.25. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs. The interpretation plots were then digitised from the rectified data plots.

Notes in parenthesis refer to the numbered anomalies in the accompanying interpretation plots (Figures 11.26 to 11.30).

Description

RM15 resistivity survey- Figure 11.4

The data shows quite strong variation with a range from 234 to 1739 ohms. This is in part due to probe contact issues producing anomalously high readings. Grids 1-4 and 6-9 are generally uniform with a few distinct anomalies. There is a linear low resistance anomaly running along the centre line of the survey, from about midway

down the boundary between Grids 2 and 7 (r1) that runs into a cluster of high and low resistance anomalies about 10m in radius centred on the intersection of Grids 3,8,4 and 9 (r2). There is also a linear low resistance anomaly running along the boundary between Grids 3 and 4 (r3) that again joins this cluster. The cluster itself (r2) is characterised by a general zone of low resistance at the outer edge, about 5 thick that gives way to a smaller interrupted ring of high resistance readings about 2m thick. The centre of the anomalies, with roughly a 2m radius is generally lower than the back ground readings on the site. There is one outlying anomaly, just north west of the centre of Grid 8 which is a small low resistance anomaly, about 5m across with a high resistance centre about 2 across (r4). There are a number of smaller, low intensity high resistance anomalies, two along the intersection between Grids 1 and 6 (r5 and r6) and two within Grid 9 (r7and r8).

The most visible anomaly is a dual linear anomaly that runs along the boundary between Grids 4 and 5 and Grids 9 and 10 (r9). The eastern side is a generally higher resistance feature with some variations in thickness along its length. At its widest it is perhaps 3m. Immediately to the west of this there is a thicker (roughly 4m) area of higher resistance values that is more uniform in width. The general character of the results to the west of this anomaly (Grids 5 and 10) is more contrasting than the rest of the survey, with a general speckling of higher resistance responses that do not seem to be features, not forming any regular shapes or patterns.

FM36- Figure 11.5
The gradiometer results are also generally quiet, with a 'flat' response from much of the site. Even before operator errors were removed from the data the range of values was low, from -11.55 to +21.05nT. There are no clearly archaeological, anomalies, but there are areas of disturbed responses. The first of these is intermittent and runs along the border between Grids 4 and 5 and Grids 9 and 10 (g1), mostly just within Grid 4 and Grid 9. It is a jumbled response of readings that are both higher and lower than the background.

There is another area of disturbed responses that centres on the intersection of Grid 3, 4, 8 and 9 (g2) that is roughly 10m in radius. Within this zone there are a number of positive responses, some of which are up to 2m across. There are two significant

bipolar responses at the edges of this zone as well, one at almost the centre (slightly to the Northwest) of Grid 8 (g3), and one spread out over 5m midway along the intersection between Grids 8 and 9 (g4). The north east corner of the survey appears to have a slightly more positive response over a discrete 10 x 3m area (g5).

EM38 survey

Vertical quadrature phase response- Figure 11.6

The raw data shows only very small variations, up to about 6 mS/m, and generally low conductivities with the average value in the raw data being 3.4 mS/m. The background is fairly uniform, with little variation. There are no discrete high or low conductivity responses, but there is a zone with both higher and lower conductivity anomalies grouped together in a noisy zone, centred on the intersection of Grids 3, 4, 8 and 9 (q1). There is also a slight Northwest running linear anomaly over about 10 which is both high and low conductivity, running through Grids 1 and 5.

Vertical inphase response- Figure 11.7

The data appears to be very noisy with a lot of variation, but this is because the variations are so small the general noise of the background shows through due to the lack of any strong features. There are three areas of higher readings that occur over more than 1 reading point (1m), all within or on the edge of Grid 8. The first is just to the north west of the centre of the Grid (i1), the second roughly midway along the intersection between Grid 8 and Grid 3 (i2) (and partly being in Grid 3), and the third is about 7m in from the southern edge of Grid 8, and about 5m from the western edge (i3).

GPR 500 MHz survey

For the individual timeslices, see Figures 11.10 to 11.25, for interpretation see Figure 11.30.

Rather than describe each slice the major anomalies of archaeological significance are discussed, as is the general character of the data. The depths given here are approximate and based on an assumed radar velocity of 0.08m/ns, and are summarised in Figure 11.9 The anomaly id's in parenthesis refer to Figure 11.30.

In the first timeslice (timeslice 1/ 0 – 0.16m) there is a clear zone of different response; most of the response in this slice seems to be noisy and high amplitude but there is a clear area formed of one large zone covering most of Grids 3, 4, 8 & 9 linked by a linear continuation to a smaller zone centred on the border of Grids 1 & 6 with offshoots to the north and south (rad1). The whole zone is free of the noisy response that seems to be common to the rest of the slice.

At the border between Grids 1 & 6, midway along, an isolated high amplitude response appears at roughly 0.2m and continues to about 0.5m (timeslices 2 -6) (rad2). It is roughly circular and about 4m in diameter.

Centred on the junction between Grids 3, 4, 8 & 9 there are a series of curving anomalies made up of discrete round high amplitude responses (rad3a, b, & c). Rad3a & b possibly form part of the same circular feature, while rad3c seems to run within the other two. None of the circuits are unbroken and in the centre of the anomalies there is a clustering of high amplitude responses that makes unravelling the separate circuits difficult. These anomalies are present from 0- 0.5m (timeslices 1-6). The high amplitude responses in the centre of these (rad6) starts at about 0.3m and continues, to a depth of about 0.75m, increasing in size with depth (timeslices 5-9). The maximum extent of these anomalies is a roughly circular area about 20m in diameter. The individual arcs of broken high amplitude responses are at most 2m wide, but describe the outer edges of this large area.

Adjacent to (rad1), slightly to the north, at a depth of 0.2m a semi circular anomaly of intermittent high amplitude responses starts and continues to a depth of 0.6m (rad4a) (timeslices 4-7). At 0.45m a high amplitude response that would be at the centre of this circle appears (rad4b) and persists to a depth of 0.9m (timeslices 7-11). The semicircle is about 11m across and the arc of readings forming it about 1.5m wide. The central anomaly is about 2m across.

A linear area of higher amplitude responses runs along the top edge of Grids 5 and 10 (rad5). This starts at 0.3m and continues to a depth of 0.9m (timeslices 5-11). It is at its widest 2.5m wide.

There are no coherent features that appear to be archaeological below 1m in depth; the signal gives way to the broad slow changes characteristic of geological changes rather than the (usually) sharply delineated characteristics of archaeological anomalies. Grids 5 and 10 are an exception to this, with a great deal of high amplitude responses starting at 0.3M (timeslice 5) and carrying on over the whole depth of the survey, getting stronger and more extensive with depth. These responses are also more concentrated the further west/ downslope in the Grids. There is a small area which seems slightly different in character. A number of high amplitude responses that start relatively early, and up near the top/eastern edge of Grid 10 (rad7). These first appear at 0.6m and carry on to about 1m where they are lost into the general noise of the Grid. There seem to be two or more paired high amplitude anomalies laying either side of an east/west line, but given the general character of the Grid these anomalies are only tentatively identified as being of archaeological interest.

In the southeast corner of Grid 5 there are some high amplitude reflections that start slightly higher in the profile than the general noise, and do appear to have some matches in the resistivity data.

Interpretation

Please refer to the interpretation plots, Figures 11.24 to 11.28, and note that the references in the text correspond to marked anomalies on those plots.

RM15 resistivity survey- Figure 11.24

The lower resistance anomalies r1 and r3 lie in the same location as paths on the surface; these are shown in the interpretation plot for comparison purposes and were surveyed with dGPS from their visible characteristics in the field, not from a map. The paths were generally covered in much shorter grass than the rest of the survey area and it could be this allowed greater soil moisture at the surface than the very long *Molinia* grass that covered the rest of the site. This may also explain the generally lower resistance response in and amongst the stone circles (r2); the vegetation there is similar. The ringer of higher readings within r2 seems to correspond to the more tightly laid out central ring of the monument (see Figure 11.3). Responses on the site seem to be slightly inverse to what would normally be expected; the high resistance part of r9 is actually the leat itself, while the bank shows as a low resistance feature.

This is possibly because the soils are relatively shallow and so any cut features are presenting as higher resistance and any mounded features lower as a result. It could also be due to topographic effects. The response at r4 seems to focus on the largest stone of the setting; enough water had collected in its setting that it had reeds growing around the base of it and the peat soils had eroded away in places. The two high resistance anomalies, r7 & r8 seem related to the hollow surveyed in that location. Anomaly r6 is the cairn mound and r5 could be a related feature or a natural outcropping hidden in the peat.

Grids 4 and 9 showed some striping in the response. The direct cause of this is unclear but it seems likely that the interfering presence of the stone circle in such shallow soils, coupled with very saturated field conditions have caused this. A twin probe array is directionally sensitive, but this is not normally apparent in surveys on 'normal' soils and where the reading intervals are 1m x 1m. In this instance, the presence of shallow conductive soils overlying a relatively non-conductive layer, the sensitivity of the array increases as the current flow is constrained. Under these conditions the array should be kept in the same orientation for the duration of the survey. This was not possible when negotiating the area immediately to the east of the central circle as the outer rings of the circle and the heads of the putative stone rows are very tightly packed together. The striping effect, noted here, is worst in the north west quadrant of Grid 9, where the array had to be turned frequently to fit between the tightly spaced stones in the outer circles and stone rows.

FM36 gradiometry survey- Figure 11.25
It is very difficult to say whether the anomalies showing in the gradiometer survey are a product of buried features, or due to heading errors by the operator negotiating the leat (g1) and the stone circles (g2). The latter is favoured as an explanation as there are no clear areas of enhancement in the survey and the strongest anomalies (g3 and g4) correspond to two of the largest (and hardest to navigate) stones of the stone circles; these stones are both broad and high and so interfered with the normal traverse of the instrument and operator.

It is possible that the anomalies are being caused by the stones themselves, free of peat and weathered granite they might have some thermoremnant magnetism that is

contributing to the responses seen. Either way, it does not seem that the gradiometer survey was responding to any sub-surface archaeology. This does not mean there are not features on the site; for example, a ditch fill that might be expected to show up due to anthropogenic enhancement of the soil on a settlement site may very well not show here as there is (as yet) no evidence for settlement on the site, and so less likelihood of enhanced ditch fills. The same reasoning applies to pits and stone sockets; if there is no magnetic contrast, they will not be visible. Furthermore, wet conditions have been shown to inhibit the anthropogenic enhancement process (Thompson & Oldfield 1986).

There does not seem to be an archaeological explanation for the enhancement at g5; there are no corresponding anomalies in any of the other surveys and the anomaly has no obvious shape or cause. As it occurs at the start of a grid, it is possible it is an artefact of survey errors that has not been dealt with fully by the data corrections made.

EM38 survey

Vertical quadrature phase response- Figure 11.26

The noisy zone (q1) is in the area of the stone circles. The mixed response is likely to be due to very high and low conductivity features (the sockets and the stones in them) being closely placed together, at a smaller resolution than the survey was conducted at. The resistivity surveys were done at 0.5m intervals and it seems that if the EM survey had been done in the same way, the results might have been more comparable. The vertical dipole orientation is sensitive to a greater depth than to 0.5m twin probe array however, and, given the generally low conductivities observed, it seems this instrument was responding, at least partially, to the less conductive substrate.

Vertical inphase response - Figure 11.27

The slight magnetic enhancements at i1, i2 and i3 roughly correspond to the outer circle of the stones; it is possible that there is some limited enhancement of the soils in the sockets of the largest stones; the livestock on the moors use the stones for shelter and as rubbing posts and have churned up the soil in the sockets of some of the larger stones. There is a gradiometer anomaly (g3) at the same location as i1, though this could be due to a heading error. Another explanation could lie with the 1920s

reconstruction of the monument; we do not know how the stones were re-erected or if off site soils were used (Petit 1974).

GPR 500 MHz survey- Figure 11.28

The very first part of the GPR results seem heavily influenced by the vegetation on site. Almost all of the area not contained within rad1 was covered in thick *molinia* grass, whilst the area within rad1 was short grass. The molinia tussocks were quite substantial and posed some problems for the survey in terms of tipping the radar antenna about a lot. Some of them were more than 0.3m proud of the ground surface. Rad1 then appears to be a reflection of the surface topography, showing the areas compacted and kept relatively free of vegetation by the humans and animals that visit the site.

Most of the radar results need to be examined with the surface topography in mind. Anomaly rad2 is clearly the cairn. What is interesting is that at greater depths when the geology becomes visible there seems to be an outcropping here as well. It suggests that the cairn was built on an existing outcropping or rise in the ground.

Anomalies rad3a, b and c seem to be the outer circles of the multiple stone circles. The lack of clearly defined inner circles contributes to the argument that at the centre of the circles was some sort of banked cairn, as does the slightly deeper anomaly rad6. Whether the discrete high amplitude responses that make up these arcs are buried stones or reflections from stone sockets is uncertain, as is whether they reflect standing stones or stones that were missed in the 1920's reconstruction. It has not been possible to match the only extant plan of the monument to the plots and plans produced to date as the shape of the hollows on the site seems to have changed since the 1980s when it was recorded (Figure 11.29).

The leat bank shows clearly as anomaly rad5, but at greater depth than expected; it was anticipated that the top of the bank would have strong reflecting properties, especially if it were partly constructed using cleared stones.

Anomalies rad4a & b are challenging to interpret. The semicircular anomaly is bisected by one of the changes in survey background mentioned earlier. However,

even when the two blocks are processed separately and compared, there is no matching half to the anomaly, so it does not seem to be a circular ditch feature (perhaps a cairn with a ditch or some sort of barrow) and it is too wide to be a hut circle. The pattern seems to be too regular and abrupt to be geological and it occurs in the same depths as much of the archaeology on the site, seemingly too shallow to be geological in origin. Thus it is determined to be an archaeological feature, but without any interpretation being possible from the data at hand. It did not appear in any of the other datasets, so there is no suggestion of magnetic enhancement associated with settlement or with a low or high resistance anomaly (which would suggest some sort of earthwork or structure).

Anomaly rad7 is similarly challenging. It is only tentatively identified as being of archaeological significance because it appears higher in the profile than other 'geological' anomalies in that part of the survey, and because it is in the expected location of the stone rows posited to continue downslope of the stone circles and leat. There do appear to be two lines of higher amplitude responses with a gap between, but there are so many anomalies within Grid 10 (and Grid 5) due to the different nature of the soils and subsurface on this part of the site, that it is by no means certain that this interpretation is correct. There are a number of possible interpretations of this noisy data, but human perception is prone to seeing patterns in random data.

11.1.5 Case-study specific conclusions

The degree of success of the project should be assessed against the aims established with the DNPA.

- To establish the fidelity of the antiquarian 'reconstruction' of the monument by looking for other stone settings or buried features

The surveys have suggested that the monument has no substantial subsurface anomalies that contradict the reconstruction work done, or suggest a radically different shape for the monument. The surveys did not prove to be of fine enough resolution to show individual stone sockets, though when the topographic surveys are refined, the radar data may yet show these. The overall form of the monument seems to agree with the geophysical response.

- To establish if there was a previous monument on the site, and if so shed some light on the possible sequence of construction

The radar survey located an anomaly just to the north of the known cairn which may prove to be an earlier or contemporary monument on the site. However, the survey alone has not been able to confirm the nature of the features.

- To prospect for features now not visible above the blanket peat, and examine the original landform prior to peat growth.

See the point above. Also, the surveys have revealed that the character of the soils on the site seems to be very different below the leat, in contrast to the area above it. This is possibly related to moisture being held in the leat leading to less growth of peat. This has potential consequences for any buried archaeology; if the site has been progressively drying since the construction of the leat it is possible soil has been lost from the Bronze Age land surface and the archaeology has been truncated.

- To examine the relationship between the stone circle and the associated cairn.

There did not appear to be any archaeological features between the cairn and the stone circles; no signs of a buried stone row or other 'avenue' type features. There is likely to have been some sort of relationship between two monuments, being from the same period, albeit a long one, (and thus visible and known in the landscape), but the geophysical survey results indicate that this was not formalised in a physical link between them.

- To examine the 'stone rows' on the site and see if any continuation of them can be detected and planned.

The previously mentioned changes to the soil character below the leat have meant that it was not possible to distinguish any buried stones or sockets in this area. The radar survey tentatively identified some anomalous responses in the expected location of these, but the interpretation is very cautious and should ideally be ground-truthed; it is

unlikely the anomaly would be identified as archaeological, had it not been in an 'expected' location. Geophysical survey alone has not been able to answer this important question about the site.

11.2 Ground-truthing excavations and re-interpretations

In October 2008, thanks to funding from English Heritage, arranged through DNPA it was possible to conduct ground-truthing excavations at Yellowmead to examine the conclusions of the geophysical surveys, and try to answer the questions that remained following the surveys.

The excavations took place from 12-16 October, a relatively dry period. It had been dry for the preceding 10 days, and remained dry until the 15 October when some light rain in the early part of the day caused flooding problems all day, as water flowed through the peat and collected in the leat from much higher up on the moor.

11.2.1 Excavation strategy

The excavation was highly targeted, with four trenches designed to look at specific geophysical anomalies and/or topographical features. Some modifications were made to the trenches (Figure 11.30) once they were laid out and their exact relationship to the slope and upstanding archaeology could be seen.

Table 15: Trenches and aims at Yellowmead Down

Trench	Justification
1: Adjacent to the cairn (monument 10749)	4 x 3m trench located over geophysical anomaly adjacent to the small cairn to determine nature of the reflectors in the GPR data and establish if of archaeological interest.
2: Through line of outer ring of stone circle and adjacent to extant hollow (monument 10748)	5 x 3m trench located over area of low resistance and GPR anomaly to try to confirm if this is part of the original Bronze Age monument, or Medieval tin prospection pits. This may also clarify if there is a 5th circle, given the presence or absence of stone sockets
3: Through the leat	7 x 2m trench to examine the structure and stratigraphy of the leat, and to look for a buried soil under the bank to help understand the stratigraphy over the site as a whole, as well as for environmental sampling.
4: To the far side of the leat in line with the presumed stone rows	4 x 4m trench to establish the character of the soil this side of the leat as seems different in surveys, establish site formation process; does this represent clearance in the Bronze Age or by the tin miners? Also to examine area for stone sockets for presumed stone row and confirm or deny its presence. The GPR shows part of a possible curving feature of the same dimensions as the main circle in this area.

A detailed dGPS (differential Global Positioning Satellite) survey was also taken to better establish the locations of the surface visible stones, to assist in the re-interpretation of the geophysical surveys; see Figure 11.30.

11.2.2 Field observations and excavation interpretation

General observations

In general, the turf-depth was surprisingly great over most of the site, thicker than 10cms in trenches 1 & 4 and up to that in 2 & 3. There was a very thick, matted root mass for the grasses on site that came down onto a layer very rich in small chippings of quartz that seem to have decayed out of granite. The soils followed much the same sequence over the site (discussed in terms of individual contexts below), with this root layer immediately followed by a short quartz-rich horizon that was almost black when wet but that dried to a very dusty grey. This was followed by a layer with less granite and quartz chips that in the area below the leat seemed to give way to a slightly gleyed horizon, and elsewhere came straight down to the underlying yellow weathered granite layer, which in all of the soil pits dug into it, had some degree of iron panning. As a result this layer ranged from very bright yellow-brown to deep reds and pinks. It had much larger stony inclusions than the other upper layers. It is this layer that is referred to as the 'natural' in the descriptions that follow.

The area below the leat had a great deal of worm activity, for what we had assumed to be a generally acid soil system. The thickness and very closely matted nature of the active root layer across the whole site means that is unlikely any cut features would be distinguishable in the soils as bioturbation will have greatly blurred them all, even over relatively short timescales, for example, since the reconstruction 90 years ago.

Trench 1- Figure 11.31

Observations

There are significant granite stones lying at the base of the 'soil' above the natural that did not appear to be outcroppings of unweathered granite. There was also a compacted zone of decayed granite between some of the large stones and smaller adjacent ones: it is possible this is the remains of packing from a stone setting. None of the revealed stones were convincingly structural or apparently '*in situ*'. Any archaeological interpretation of the trench is therefore incredibly difficult.

Interpretations

In synthesis with the material recorded in the other trenches, it does seem likely that the stones present in this trench were placed, perhaps not in these positions, but nearby, by humans in the past. There were too many large stones, in a very shallow position, apparently in the soil, rather than outcropping from the natural, when compared to the largely blank areas exposed (especially in Trenches 3 & 4 where there can be little argument for 'clearance' unlike Trench 2), to assume this is the usual appearance of the immediate subsurface. However, we did not lift any of the stones to attempt to confirm this interpretation as our remit on site was shallow ground-truthing evaluations. Given the lack of any obvious form or structure in the placement of the stones, it is not possible to offer, at present, an interpretation of the apparent archaeology in this trench.

Table 16: Trench 1 Contexts, Yellowmead Down

Context number	Description (as recorded in the field)	Munsell colour	Inclusions	Sample number	Maximum thickness
C001	Dark Brown to Black Peaty Clay, Loose Compaction, Topsoil	N2.5-1 5YR	Infrequent quartz flecks (sub mm)	N/A	7cm
C002	Mid Brown Peaty Clay (Sandy) Firm Compaction, Lower Subsoil	7.5YR 4/6	Occasional quartz flecks (1mm)	22	Natural- not investigated
C003	Dark Brown to Black Peaty Clay, Loose Compaction, Subsoil	2.5-1 5YR	Moderate quartz (1mm)	1	20cm
C004	Mid Brown, Peaty Clay, Firm Compaction, Lower Subsoil	2.5-1 5YR	Moderate quartz (1mm) Some small stones (5mm)	2	2-3cm

Trench 2- Figure 11.32

Observations

This trench had a generally more compressed soil profile than Trench 1, with the colour change indicating the end of the 'soil' (C005) and the start of the very stony humic layer (C006) being much more shallow. However, at around 3.2m in from the eastern edge of the trench and 0.7m from the western edges there was a change in the soil, not detectable in plan as it had very poorly defined edges, visible in the north-facing section of the trench (but not visible in the opposite section). This change was gradual and replaced the normal sequence in a small part of the trench with a very organic, bright brown deposit with visible plant remains throughout; in places it

looked like compressed saturated straw. This was roughly in line with the fourth (outermost) circuit of stones, and there were some isolated granite fragments nearby. The soil profile in this location then followed the sequence observed elsewhere on site, but at greater depths: the base of this deposit was at roughly 25cm below the surface and when probing to take bulk samples the 'natural' orangey layer was located at least a further 10cm below, unlike in the rest of the trench (see Figure 11.82).

Located at the change between C005 and C006 as described above, there was a large stone, of a similar size to the uprights of circle 2 (and in line with them), recumbent. There was no apparent socket. At the easternmost end of the trench there was a very shallowly buried stone, resting on a mixture of smaller pieces of granite, and soil. There were several large chunks of granite. This was left unlifted, for reasons already discussed above.

Interpretations

The feature revealed in section seems to be a natural feature, rather than the remains of a cut feature. It seems to have been created by the increase in moisture around the base of a stone lying recumbent or perhaps partially subsumed, on the surface for a considerable length of time. This has considerably altered the soil profile immediately below where the stone was lying. Some stones on the site act as strong enough water traps that they have reeds growing from their sockets. This interpretation is strengthened by the location of the feature in the line of the first circle, and very close proximity of a stone from the outer circle.

The large (complete?) recumbent stone in the centre of the trench is interpreted as being a fallen (and not reconstructed) stone from circle 2 given the general lack of other stony material in the trench, its location adjacent to stones two stones in the second circle (Figure 11.32), and its shape and size. This interpretation gives more validity to the 1921 reconstruction, as this stone lies about 10cm below the surface, but was not re-erected, lending credence to the account that stones were simply re-erected where they lay, rather than being actively dug for and moved about.

The collection of stony material in the eastern end of the trench seems to partly be decomposed parts of a larger piece of granite. Its location corresponds to the very

edge of a generally high amplitude noisy zone in the GPR data, just below the surface, and just beyond the edges of Circle 3. It is possible that this represents the very edge of a spread of granite material just below the surface; perhaps the spread remains of a central cairn.

Table 17: Trench 2 Contexts, Yellowmead Down

Context number	Description (as recorded in the field)	Munsell colour	Inclusions	Sample number	Maximum thickness
C005	Dark Brown to Black Peaty Clay, Topsoil	N2.5-1 5YR	Organic Matter, Infrequent quartz (sub mm)	21, 5 (M1)	7cm
C006	Dark Brown to Black Peaty Clay, Subsoil	N2.5-1 5YR	Moderate quartz (1mm)	3, 5 (M1)	14cm
C007	Dark Brown with a Green Hue, very high organic content- Organic layer (formed under recumbent?)	n/a	Very occasional quartz (sub mm)	4, 5 (M1)	16cm
C008	Mid Brown (orangey hue), Sandy Gravel	7.5 YR 4/6	Moderate quartz (1 mm), occasional small stones	20	Natural

Trench 3- **Figure 11.33**

Observations

This trench located no buried stones or any apparently prehistoric features. The cut and bank of the leat were clearly visible, as was the structure and construction of the leat. It had been suggested from the geophysical surveys that the leat bank might have a stone core, perhaps from clearance or stone encountered in the digging of the leat. This proved not to be the case; the bank was formed of a core of very dark, humic soil with well developed columnar peds, which was overlain by a deposit of the upcast 'natural' where the leat had been actively cut down into the relatively impermeable (and brightly coloured) substrate. There did not appear to be a buried soil, with the base of the leat bank deposit coming straight down onto C010 (equivalent to C003, C006 & C014 across the site). The leat cuts about 10-15cm down into the substrate, and when taking bulk samples it was noted that if the iron panning observed on the site was disrupted by this process, it had reformed in the time of the leats' operation. The leat still acts as an interruption to the water through-flow on site. It took only 20 minutes of light rain to keep it full of water, from run off, for a whole day.

Interpretations

No prehistoric archaeology was expected in this trench, and the lack of other large stones lends weight to the interpretations of Trench 1 and Trench 4's stones as being deliberately placed. The lack of stones in the core of the bank suggests a re-interpretation of the radar data is needed, and that the natural substrate may be producing stone-like reflections. The absence of a buried soil, under the bank was not expected. It is possible that the whole area was stripped of turf as part of the construction process, it is also possible given the well developed peds noted, that the effectively 'sealed' deposit, under the upcast natural, has experienced physical and chemical changes that make any buried soils undetectable. This layer of upcast clayey material is patchy in places but does seem to have been used to deliberately cover the upcast peat; and without stones, this bank has lasted for centuries under reasonable hydrological pressure. Certainly, following rain the natural substrate seemed to be relatively impermeable. The leat, as mentioned above, still functions as a water trap, though a lack of maintenance means it no longer flows to the southerly tin streaming area, though it does flow north to a similar area (see Figure 11.2), following the contour of the hill.

Table 18: Trench 3 Contexts, Yellowmead Down

Context number	Description (as recorded in the field)	Munsell colour	Inclusions	Sample number	Max thickness
C009	Dark Brown to Black Peaty Clay, Loose to Medium Compaction, Topsoil	N2.5 – 5YR	Infrequent quartz (sub mm)	6, 9 (M2)	10cm
C010	Dark Brown to Black Peaty Clay (Sandy), Firm Compaction, Subsoil	2.5-1 5YR	Moderate quartz (sub mm) Occasional feldspar (5mm)	7, 9 (M2)	Max exposed 6cm
C011	MIXED/MOTTLED UPCAST 1. Reddish Brown Moderate compaction, sandy clay 2. Dark Brown to Black, firm compaction, columnar peds in places, peaty clay Generally 1 overlies 2, but is patchy and irregular.	1. 3-4 5YR 2. N2.5 (Gley)	1: Infrequent feldspar (5mm) 2: moderate quartz (sub mm)	1: 8b 2: 8a 9 (M2)	32cm
C012	CUT OF LEAT	N/A	N/A	N/A	See section for dimensions
C017	Strong Brown (Orange Hue), Sandy Gravel, Firm Compaction, some evidence of Iron Panning in cut for leat.	7.5YR 4/6	Occasional quartz (1mm)	14, 9 (M2)	Natural. Only exposed in cut for leat, rest of trench excavated to top of C010.

Trench 4- Figure 11.34

Observations

Lifting the turves in this trench was problematic, as C013 was lifted with them, and in places parts of C014, as there were lenses of more quartzy deposits that seemed to adhere to the bottoms of the turves. Two distinct sets of stones were discovered, and significantly, one group appear to still be in their original sockets and upright setting. There is a cluster of five stones, apparently in a double arcing structure, with one outlier, still 'upright' in their setting, though very small- they are definitely in the ground 'end down' rather than lying flat like all of the other stones exposed by the excavations. They are set in two slight arcs, the inner with two stones roughly 0.4 and 0.2m long and 0.15 and 0.2 m wide respectively. These two are set in line with each other (the long axis of the first being aligned roughly east-west), about 0.5m and 0.25m from the southern edge of the excavation, with the longer one being furthest away and the east-most of the pairing. Set about 0.5m back from each of these (so preserving the curve/ staggering) are two more elongated upright stones, of similar

size, about 0.25m 'long' and 0.1m wide. Again, the long axis of the westernmost one is aligned roughly east-west, and the eastern most slightly off this alignment, more north-east, south west. Immediately (0.3m) to the north of this stone is the fifth of the exposed arrangement, which is of similar dimensions, but aligned much more east-west. These stones were just visible in the initial cleaning of the trench, and were exposed to the top of the colour change, as described above. Around 10cm of the tallest was exposed.

The only find of the whole excavation (F001), a flint scraper, was discovered just to the west of this setting, in the area not taken down to the bottom of C014. The find came from the base of this context as it was discovered when the trench was being cleaned for photography. The findspot is located 0.6m in from the southern edge of the trench, and 1.6m in from the western edge. It lies about 0.7m east of the south-west most stone of the five stone setting. The base of C014 could be interpreted as the level of the putatively Bronze Age topsoil, given the relative position of the newly discovered stones. See Appendix B for the specialist report on this find provided by Jane Marchand, and Figure 11.35 for a scale drawing by SJ Hathaway, who also kindly drew up the trench plans.

The spit excavated along the northern edge of the trench revealed several large (relatively) recumbent stones, the largest 0.7m long and 0.5m wide (though apparently lying on its side, unlike those discussed above). There were three large stones, one only half exposed in the section, and a scatter of apparently associated (either packing material or larger stones that have decayed and broken up in-situ). These appeared to be on the same downslope line as the upright stone that the eastern edge of the trench had to be cut round to avoid, and of a similar size. Assuming the larger stones are recumbent roughly *in situ*, they seem to have a reasonable regular spacing between them ranging from 1- 1.5m (taken from centres of stones). This rough interval also exists between the easternmost one in the trench and the upright surface stone, about 1.2m.

In the 2m stretch of the excavated spit between the most outlying smaller stones of the northern group, and the northern most stone of the southern group, no features were identified.

Interpretations

The northern strip of large stones and associated smaller ones appears to confirm the presence of stone rows, at least one, running down from the monument. The larger stones are interpreted as being recumbents, roughly *in situ*, and the smaller stones the remains of their packing or settings, with the granite perhaps having broken down and fragmented over time in the wet soils. They are in line with stones that have been reconstructed adjacent to the monument, and with at least one further stone downslope of the leat, and they are of similar dimensions.

The southernmost group is difficult to interpret at present, as it could be either a further stone row, of an 'avenue' type configuration, though there were not any obvious further stones to the east or west of these showing into the base of C014. They would also be slightly off-line of the slope and the monument. They may perhaps be part of a cairn or further circular setting immediately to the south of the excavated area, but again, there is a lack of stones to the immediate east and west that prevents any larger pattern being extrapolated at this stage. We can however, be certain that these stones are *in situ* and upright, and so deliberately set in place by human beings, most likely in the Bronze Age, given the period of the other features on the site, and the close proximity of the flint scraper.

The 'blank' area in this trench was also useful; below the leat, the eastern end of Trench 3 was devoid of any large stones, as was the apparent majority of Trench 4. This lends weight to the interpretation of the stones in the northern edge of the trench being the remains of a deliberate construction by humans, rather than natural outcroppings or boulders, as these are not seen to be a general characteristic of the subsurface at this level.

Table 19: Trench 4 Contexts, Yellowmead Down

Context number	Description (as recorded in the field)	Munsell colour	Inclusions	Sample number	Maximum thickness
C013	Dark Brown- Black Peaty Clay, Loose to Medium Compaction, Topsoil	N2.5-1 5YR	Infrequent quartz (sub mm)	15	8cm
C014	Dark Brown to Black, Peaty Clay (Sandy), Firm Compaction, Subsoil (gleys to bluish grey in places at base)	2.5-1 5YR	Moderate quartz (1mm), Occasional feldspar (5mm)	16, 10 (K1), 11 (K2)	11cm
C015	Red/Brown Oxidised layer (Iron Pan), Very Firmly Compacted, Undulates Sharply	N/A	N/A	17, 10 (K1), 11 (K2), 12 (K3)	1-2cm
C016	Mid Brown (orange hue)/ Strong Brown, Sandy Gravel, Firmly Compacted, Natural Subsoil	7.5YR 4/6	Frequent small stones (5mm), very occasional quartz (1mm)	18, 11 (K2), 12 (K3)	Natural

Conclusions

Archaeologically interesting deposits were discovered in all of the trenches, and though some of them have proven very hard to offer interpretations for, the interpretation of what was significant from the survey data seems to have been vindicated. Trench 1 proved the hardest to understand, possibly due to its relative size to the expected features, giving a key-hole examination. It had so much in it that it has been difficult to say if this is a reflection of the natural subsurface on this part of this site or is archaeological material.

Trench two successfully proved there is no ditch, and that the outer curving anomaly in radar surveys is in fact related to the outer circle and disturbance of the ground in its reconstruction. It also located a recumbent stone from the 3rd circle, missed in the original reconstruction of the monument. This has increased confidence in the reconstruction of the monument as it appears the archaeologist did not go digging for stones or moved them very far to re-erect them. No features were discovered that are grossly at odds with the visible surface archaeology of the stone circles. The interpretation of the site as a cairn with outlying circles seems to have been vindicated by the material in the very eastern part of the trench (granite rubble), which matches up to an extensive radar anomaly, high up in the profile, extending over much of the inner two circles.

Trench 3 provided the expected section through the bank, which challenged the assumption of a stone core that was based on the survey results; it seems the redeposited natural provides quite strong GPR reflections. This has implications for the wider interpretation of the radar results on the whole site, and further processing of this data and investigations are needed. No buried palaeosols were readily identified, but a monolith sample and bulk samples were taken for further analysis (see sections 11.2.3 and 11.2.4).

Trench 4 was quite speculatively located, over some anomalies and where archaeology was also expected, given the projected line of the stone rows. It seems to have proven at least one stone row (in the north of the trench) and another potential one, or some other setting in the southern part of the trench. Given the small area exposed, analysis of the soil samples and reconsidering the radar and resistivity data was necessary to try to understand better how the different geophysical responses on this part of the site arose and how features might be better distinguished, particularly in the GPR data.

Overall, the excavations agreed and reinforced the interpretation of the geophysical surveys. No radical revisions to the archaeology of the site have been suggested, and the intervention has shown that the centre of the circles does seem to contain cairn-like material, in agreement with the surveys. The change in the character of the soils below the leat inferred from the surveys was confirmed in field observation. However, the excavations also suggested caution was needed when inferring 'stoniness' on the basis of the GPR results, as lenses of quartz and the upcast natural within the leat bank were found to cause similar reflections to buries stones.

11.2.3 Laboratory methods

Samples were taken of all contexts where possible, and some intact samples (two monoliths and three kubiena tins) were taken of the more interesting soil sequences on the site, to allow more detailed characterisation and investigation. See Figure 11.36 for the sampling locations.

Bulk samples

The bulk samples were halved, with one half being retained field-moist, and the other being air dried for a week, with the resultant loss in water recorded.

These dried samples were then used for all of the further tests discussed below.

Particle Size Distribution (PSD), Loss on Ignition (LOI) and Moisture Content (MC)
The whole air dried sample was weighed and dry sieved through 5.6mm and 2mm sieves to give the percentage of small and very small stones. Sub samples of the 2m fraction were then oven dried at 105°C for at least 12 hours, and reweighed to measure the amount of interstitial water, then ashed at 450°C for at least 12 hours to remove all organic material.

They were re-weighed to allow a calculation of Loss On Ignition (LOI), which gives us the percentage of organic material in each sample. Whilst heating the samples can have a detrimental effect on the clays, 450°C should not be hot enough to fire the clay particles together, and thus have an effect on the Particle Size Distribution (PSD) method employed, the pipette method. However, the samples were also processed by sedigraph to allow a better estimation of the silt/clay contents; see below for further details.

These ashed samples were then run through the Bournemouth University house-method of PSD. The samples were blended with distilled water containing a 1% solution of sodium hexametaphosphate, to prevent the clays flocculating. The samples were then wet sieved to 63μ, using a hand pumped water spray. One litre of water was used on each sample and the material and liquid collected in a one litre settling tube.

The 2mm- 63μ fraction was rinsed from the sieve and retained, and placed in the 105°C oven until dry, then weighed, to give the sand fraction.

The samples in the settling tubes therefore contained only the silt and the clay, and following the pipette method, they were vigorously mixed and left to settle for exactly 5 hours, at which time the top 10cm was pipetted off. This 10cm contains the clay in the sample, left in the suspension, whilst all of the silt particles, being larger, have already settled out. 40ml of the pipetted liquid was removed and dried at 105°C; this represents 4% of the clay in the sample, so from weighing this residue, and knowing

the weight of the original sample, and the removed sand, the weight of the rest of the clay, and the missing amount (the silt) can be calculated.

Magnetic susceptibility measurements

Sub samples of the <2mm air dried fraction were tested using a Bartington MS2 lab sensor, following the method set out in section 9.4, above. The air dried <2mm fraction was used rather than field moist samples as the soils were collected in large enough samples to make this feasible. The soils contained less organic materials and did not seem to have an anaerobic layer, reducing the possibility of chemical and physical changes being introduced by drying them out. Tests were carried out on the bulk samples only; the monoliths had been stored for a long period and the possibility of Fe contamination meant useful results were unlikely to be obtained. As all of the context were sampled, it has been possible to create pseudo- depth sequences showing the contexts in stratigraphic order, much as for the PSD and LOI tests.

Intact samples

The intact samples were limited in size so different methods had to be sought to be able to make these measurements; the pipette method requires a greater mass of dry soil than could be achieved in meaningful sub-samples of the monolith column. English Heritage kindly granted access to, and assistance from Dr M Canti with their Sedigraph machine for determining the silt: clay ratio, and where it was not possible to directly measure some properties (free moisture/ interstitial water vs. total water content), these can be inferred from the bulk sample that relates to the same context as that part of the monolith.

Particle size distribution- Sedigraph

Tests were conducted on all of the bulk samples (to correlate between methods, and try to eliminate any problems that heating the previously tested samples during the ashing phase might have caused with the clays) and 5cm sections from each of the monoliths, prepared as follows.

The bulk samples were hand sieved from the un-ashed <2mm fraction through a 63μ sieve, dry, until roughly 5g of the silt: clay sized fraction had been obtained. The sieving residues were discarded.

The monoliths were partially cut into 5cm sections and dried overnight at 105°C with the total moisture loss recorded. The top 10cm of Monolith 2 (Sample 9) was not sampled for this test as on visual inspection it was almost all fibrous organic matter including roots. They were weighed and returned to the oven for one hour to check that no further moisture loss occurred and when they had stopped loosing weight they were cooled and hand and sieved to 63μ sieve, dry, until roughly 3g of material had been collected. This was NOT all of the >63μ material in the sample, just as much as could be recovered given time constraints. The sieving reside was therefore retained, to be ashed and wet sieved to give the LOI and sand fractions (see below).

A Micrometrics SediGraph 5100 was used to perform the analysis. The machine uses measurements of x-ray intensity through a column of suspended soil material to estimate the number of particles interfering with the passage of the x-rays. It moves down the column, measuring as it goes (over about 10cm), using known settling rates to estimate the size of the particles at any given depth in the column, over time. These are then calculated into an estimation of the cumulative particle sizes, producing a log curve. The cell containing the column needs to be within a set temperature range, as the viscosity of the water the soil is suspended in makes a difference to the settling rates on these small scales. It is also important that the sample is well mixed and any tiny aggregates broken up. Thus the sample preparation is very important, and can be a trial and error process, testing different steps until an acceptable result is produced (i.e. a smooth curve with no sudden tail off as the clays flocculate and drop out of solution too early).

After some testing, a method was found that produce acceptable results with these samples most of the time. They proved to be very problematic, probably as a result of their high organic content. The organic material is theoretically invisible to the x-rays, so should not interfere with PSD estimation, but in such quantities it is possible it was either interacting with the clays in unexpected ways, or was too much of the sample by weight, so that once it was diluted and 'invisible' in the machine, the solution was too dilute for accurate measurement.

These problems were largely overcome by the following preparation method:

- A dry sample of about 2.5g was wetted in about 40ml of 1% sodium hexametaphosphate and distilled water.
- This was well mixed using a magnetic stirrer.
- The samples were then subjected to ultrasound for 9 minutes before being introduced into the machine. Too much longer in the ultrasound bath and the sample did not work, theoretically because they became too warm and changes happening in the organic compounds
- All of the samples were hydrophobic and proved quite difficult to adequately mix; sometimes they had to be run through the machine once (with unusable results), and then a second time, using machine to mix them properly, which gave a satisfactory result.

Working this way, acceptable results were obtained for determining the silt: clay ratios on all bar one of the bulk samples, and all bar one of the monolith sections.

The main problem with the analysis was that the cumulative frequency curve had a tendency to suddenly drop off just before or just after the 2μ marker (this being the threshold between silt sized and clay sized particles). In the end, very few samples produced a smooth curve with a 'natural' looking distribution, but the curve could be extrapolated from the point of sudden change, and in almost all cases, a reasonable estimation of the percentage of clay sized particles could be made. Estimations of the PSD *within* the clay fraction were not needed for this research.

Moisture content and loss on ignition

The dried sieving residues were retained and ashed at 450°C for 12 hours, allowing a measurement of LOI and then wet sieved, to give the sand fractions. The top 10cm of monolith two was also ashed, but from a wet state (due to time constraints) and so the moisture content and resulting LOI has been estimated from tests on a bulk sample of this context.

11.2.4 Laboratory results

The results are summarised in Figures 11.37 to 11.41. The Figures are given by trench/sediment sequence rather than by test as they are most appropriately considered as a group of related results rather than a series of isolated properties. As such, the following discussion of the results will first consider each of the trenches, and then examine the contrasts between them. The MS results are given together as Figure 11.41.

The soil properties examined are interrelated, in both straight forward and complex ways. The moisture content of a soil, in terms of the free water, is linked to the amount of organic material within the soil; whereas the interstitial water is more closely linked to the particle size distributions and the specific density; as it is based on the ability of very small particles to hold water around them hydrostatically. In contrast, organic material both absorbs water, and waterlogging ensures organic material does not decay, retaining more of it in the soil. The stoniness can influence the porosity, and so the moisture retention, but the relationship is not always straightforward; a deposit that was mostly small stones (such as gravel) might be expected to be well drained, but if those stones exist in a largely clay matrix, the drainage would be more impeded than for a mineral soil with less stones. We might also reasonably expect the magnetic susceptibility measurements to be related to the PSD and LOI tests. Concentrations of organic material coupled with high MS can be indicators of human influence on a soil, or an increased MS might be linked to an increase in the clays present, as the iron and manganese compounds that produce higher MS values are present in clays in higher concentrations than in other materials. Waterlogging and higher concentrations of organic material can also impede MS, or even produce diamagnetic responses (Dearing 1999, 38).

Trench 1- Figure 11.37
Trench 1 showed little change in the moisture content (MC) of the contexts with depth, with a slightly decreasing trend in the overall MC, but no big changes in the amount of interstitial water, despite there being a relatively large change in the amount of organic material, from 30% to 11% between the topsoil and subsoil. Context 2 was stonier, and the PSD distribution changes consistently over depth to decreased sand and increased silt and clay. These shifts are probably what drives the observed

increase in MS with depth; in the upper contexts there is both an abundance of organic material and sand sized particles (observed in the field to largely be quartz or feldspar). Quartz and organic matter are diamagnetic, and in large proportions, this diamagnetism may be enough to counter the ferromagnetism of iron oxides within the clay matrix (Dearing 1999, 38-41), especially given the small amounts of clay in the topsoil. As the clay component increases with depth, and the organic material is reduced, the iron oxides present in the clay, and in the form of iron panning observed in the field produce a weak ferromagnetic effect, increasing the MS observed.

Trench 2- Figure 11.38

Trench 2 shows a different profile, but with the same linkages in effect. There is a marked increase in organic content and, as a result, moisture content in context 7, with the organic content jumping to more that 50%, making this context technically a peat soil. This context shows an expected large drop in MS, but interestingly an increase in the silts and clays present. It is possible that the organic material in the context is preventing these finer particles from being washed down through the soil profile, with the fibrous plant remains acting like a sieve. In this instance it appears the large amount of organic matter present is enough to mask any increased MS from the higher clay content. In this trench, the sand/silt/clay ratio seems to otherwise remain constant over depth, in contrast to Trench 1. In this case, it seems to be the organic/ mineral ratio rather than an increase in clay contents (by proportion) which is driving the MS results. Again, at the base of the exposed sequence, there is an increase in stoniness, particularly those larger than 5.6mm. The fine fraction still dominates the mineral components however.

Trench 3- Figure 11.39

The sequence in this profile of contexts is complicated by the split in the mixed deposit that makes up context 11; redeposited soils that make up the bank downslope of the leat. There were two readily distinguished soils in the bank observed in the field and they were sampled separately, though in the field they were assigned one context as they appeared to be a single deposition event. During excavation, the bank was assumed to have been constructed by a core of upcast peaty topsoil from the cut of the leat being capped by the less permeable, more clayey underlying deposits which are bright yellow to red in colour on first exposure. This material had weathered to an

orangey colour, and a thin soil has developed over it. On analysis, this interpretation was confirmed and enhanced. The upcast orangey material (context 11uc) showed similar PSD, MS, LOI and MC characteristics to the layer it was assumed to have been excavated from (context 17). The material underlying it (context 11up) did not have a similarly corresponding context. It produced unusual MC/ LOI results, having both the highest organic content and the lowest moisture content of this sequence. It also shows a slight increase in the proportion of silts vs. clay, in very small stones (5.6mm- 2mm) and low MS. A series of factors seem to be acting here. Firstly, when the leat was created, it is assumed in the Middle Ages, the soils on this part of the site might well have been different in character, perhaps more peaty; and these soils have been preserved under the 'protective' layer upcast parent material. They may also have had more very small stones than the current topsoils on the site. The upcast parent material (context 11uc) seems to have provided some protection for the soil, and it appeared to be relatively impermeable in the field; this might be why the soil under it (context 11up) showed reduced MC despite having high amounts of organic material compared to the rest of this sequence. This context also showed very low MS, despite not being too wet; this could be due to the presence of lots of organic matter, but the clay levels are also relatively high. It is possible, that waterlogging of this soil in the past has reduced or inhibited the development of MS. Finally, despite the protective 'cap' that has helped stabilize the bank for centuries, the soils under it will have undergone post-depositional changes. This could explain the increased proportion of silt, as clays have could have been washed out and down the profile. Certainly in the field it was noted this soil horizon had large void spaces and had developed columnar peds- see Figure 11.42

Trench 4- Figure 11.40
The sequence in Trench 4 is also complex, but with more typical linkages in the measurements observed; the topsoil, for example (context 13) is very organic (65%), with a correspondingly large moisture content (75%). The mineral component is also about 50% silt, and this value stays high (largely at the expense of the sand, the amount of clay is relatively high as well) for most of the profile, but with an increase in sand and a drop in silt in context 15. The amount of small and very small stones increases with depth. The MS values are higher at the surface, despite the high organic and moisture content; perhaps the relatively low volume of sand and the

larger amount of silt and clay is having an effect here. They then fall, as observed elsewhere on the site, before picking up again at the base of the sequence where there is the least organic material present on the whole site.

General discussion

Considered as a whole, these sequences paint a complicated picture of the soils encountered on the site. As observed in the field, there seemed to be a main sequence of soils that was quite organic at the surface, but with plenty of sand and very small stones, that got coarser and less organic with depth. A gleyed layer was noticed in some places below this, forming an interface between this soil and the underlying weathered granite, which was sandy, stony and bright yellow to red in colour on first exposure. In some places this layer had a thin, undulating iron pan. The sequences from Trench 1 and Trench 4 largely reflect this sequence, but in Trench 4, the profile seems to have become elongated with the contrasts between the horizons being more marked; this is why the profile there consists of four contexts as the gleyed/ gritty layer (context 15) was much more identifiable. We will return to this contrast presently. Trenches 2 and 3 examined slightly more complex sequences; the main three, plus an intervening feature or context that the trench had been specifically placed to examine. In Trench 2, the laboratory tests on context 7 agree with the field assessment; there is an accumulation of peaty material here that has, probably by its influence on the local hydrology, extended the depth of the sediment sequence. The moisture content and organic content suggest this soil is waterlogged or close to it much of the year and that it perhaps acts a trap for clays and silts washing down through or downslope through the soil. This agrees with the interpretation of this feature as something that developed under a recumbent stone, or perhaps in an empty socket/hollow; either of which would encourage water to pool, as observed elsewhere on the site, with reeds growing from several of the larger stone sockets.

The tests on the sequence through the leat bank in Trench 3 also confirmed field observations and interpretations. The match between context 11uc and 17 showed this deposit that capped off the leat bank was indeed from the 'overcutting' of the leat into this layer. This seems to have been deliberate; the cut then having a relatively impermeable base, and the bank having a stabilising and protective cap. The bank and cut are also demonstrably a single major construction. Though the sequence does not

rule out maintenance of the leat, the soils sequence clearly shows that context 17 was only cut into and redeposited on the bank once, when the feature was created. The contrasts in the deposit immediately below this, context 11up, interpreted as being upcast soil dating to the construction of the leat demonstrate two important aspects of the soil development on this site. Firstly, they show that the 'parent' material of weathered granite is relatively impermeable compared to the overlying soils. This has implications for the movement of water through the site and the response of a lot of the geophysical techniques (see section 11.2.5 for detailed discussion). It also suggests that in the Middle Ages the soils had a slightly different character, perhaps being more peat-like than they are now.

The sequence in Trench 4 seemed to be an exaggerated version of that elsewhere on the site, with the horizons being deeper and the differences between them more pronounced. The geophysical surveys reflected this quite strongly, with the changes being sufficient to cause a different signal/noise profile for this area in both the GPR and resistivity surveys. This difference appears to be being caused by the leat. It interrupts the flow of water through the soil downslope, and has been doing so since its creation. This seems to have influenced the soil development. The exact mechanisms of this process are unclear, and out of scope of this investigation, but the effect this has had on the soil, and subsequently on the geophysical surveys is important to note as leats are common on Dartmoor and may be encountered by other surveyors.

11.2.5 Conclusions and re-interpretations

Reconsidering the geophysical data in the light of the excavations and subsequent laboratory work, it becomes clear that some of what was interpreted as reflections from stone in the GPR survey was in fact the decayed granite layer; in particular where it had been upcast to form a covering over the leat bank. It was sufficiently different (borne out by laboratory analysis) to create a radar reflection. It is therefore possible that with further manipulation, the radar data could be used to show this interface on a site-wide basis, potentially showing up any cut features and revealing more about the original landform.

In other places, GPR reflections seem to be being caused by a spread of material from the centre of the stone circles; possibly the remains of a cairn. Distinguishing between the two responses was not possible, so more work is needed to understand the relative strengths of the radar reflections in future work.

The MS work in the laboratory showed that the decayed granite layer was significantly more magnetically susceptible than the soil overlying it. This may explain the MS anomalies associated with some of the larger stones; the problems of animal-caused erosion around them has already been highlighted; bringing this material to the surface. It does not, however, explain the gradiometer anomalies in similar locations as gradiometers do not respond well to lens-shaped anomalies. Heading errors in negotiating the lager stones remain the likely cause of these anomalies.

The excavations and laboratory work showed why the resistivity surveys were less than successful. Firstly, the soil profile was relatively shallow, and the zone of maximum sensitivity of the array chosen was within the decayed granite parent, for the most part, and so only larger features (the leat) or gross disturbances (the area of the circles) were picked up with any certainty. The combination of a shallow conductive soil layer and a more impervious substrate, with the intervening resistive bodies of the many stones on the site caused some directional sensitivity in the array. This problem needs to be noted by geophysicists working in similar environments so that steps can be taken to prevent it. Future resistivity surveys in these environments should consider using a smaller array, 0.25m, or a multiple potential electrode twin array (M-PET) (Cheetham 2001) either of which would provide a more shallow focus of sensitivity, and with a reduced transect and measurement interval, stand more chance of picking up the smaller scale features that our survey missed.

The geophysical work suggested, and the excavations and laboratory work confirmed that there are significant changes in the soil profile below the line of the leat. The causal mechanisms are not clear and there needs to be further research into them. If the normal development of the soil profile has been affected here, it is likely to have happened elsewhere as well. It is vital that future surveyors are aware of this phenomenon when they are working on potentially affected landscapes.

It also appears that the leat has somehow encouraged the development of a deeper, more organic soil profile. If this turns out to be the case, then there are possibilities for differential preservation conditions on affected sites. This has implications for research, excavation and management strategies on Dartmoor.

11.3 Drizzlecombe

11.3.1 Site background

Drizzlecombe, a valley in the Upper Plym fluvial system on west Dartmoor is home to a large complex of cairns, settlements and stone rows and boasts the largest standing stone on the moor as one of the row terminals (see Figure 11.43). The entire complex, consisting of "*3 stone alignments, 15 cairns, a cist, 5 enclosures, 19 hut circles, (earthworks) and a clapper bridge lying on a gently sloping triangle of land between Drizzlecombe Brook and the River Plym*" (National Monuments Record 2000, record 24104) is scheduled and recognised as locally, regionally, and nationally important.

The three known stone rows are among the more spectacular on Dartmoor. All the rows have encircled cairns at their heads that range from 6.7m-9m in diameter. A further cairn on the same contour as the upper two cairns, and of similar dimensions has long been speculated about as being the head of a row now lost, or never built (Petit 1974, 159; Burl 1993, 113-116), with a possible terminal stone identified at almost the bottom of the slope (making this 'planned' or missing row the longest, by some way, of the complex).

Like most of the prehistoric archaeology on Dartmoor, the complex is thought to date from the Late Neolithic (2400-2000 BC) to the Bronze Age (2000-700 BC), and in places is disturbed by more recent activity by Medieval tin miners. The site, like most of the upstanding stone monuments on Dartmoor, was extensively restored in the late 19th Century (Butler 1994). The cairns all show evidence of disturbance in earlier times. See Figure 11.45 for an overall plan of the site.

The site is currently open moorland with sheep, pony and cattle grazing. It is popular with visitors and a major (unmetalled) footpath snakes up the slope between the rows. The soils are thin peaty soils over weathered Dartmoor Granite.

11.3.2 Survey aims

The specific research aim of this particular case study was to examine claims for a fourth stone row in the complex, either extant but buried, unfinished, or robbed out. Was there ever a stone row in place leading from cairn 'A'? (See Figure 11.44). This question was arrived at in consultation with Jane Marchand, from the Dartmoor National Park Archaeology service.

11.3.3 Methods and instrument settings

Fieldwork was carried out on site from the 17-20 March 2009. The fieldwork period itself was dry but cool and windy. The preceding weeks had been both very cold and snowy/wet. The ground surface remained damp to the touch throughout the fieldwork period. On the lower portions of the two grids, *molinia* grass growing in tussocks caused some issues for ground-coupling in the GPR survey, as did the upright stones of the stone row that crosses the grid.

The grids were located immediately downslope of the cairn in question (see Figure 11.45) and were angled to ensure that part of an extant row was included in the surveyed area; it was hoped this would allow a 'signature' response of the stone row to be identified. A 30m x 60m area, with the long axis lying in the direction of the slope, to maximise the potential for discovering what could have been an intermittent or incomplete feature. Unlike the other surveys, 30m grids were employed rather than two 20m grids so as to cover the likely area effectively, without having the mid-line of the grids where any potential archaeology was likely to be located.

Table 20: Instruments used at Drizzlecombe

Survey type	Instrument	Accessories/notes
Resistivity	Geoscan Research RM15(A)	
Magnetometry (gradiometer)	Geoscan Research FM256	Used in preference to the Bartington DualGrad 601 due to the greater manoeuvrability of the smaller instrument around upstanding stones and expected shallow depth of features.
Electro-Magnetic	Geonics EM38B	Used with both Horizontal and Vertical dipole coil configurations to compare depths of any detected features. Both inphase and quadrature components of the response logged.
Ground Penetrating Radar	Mala RAMAC GPR	500 MHz antennae, 100 MHz survey wheel used to measure distances.

Given the small expected size of the potential archaeology (stones up to about 1m across) 0.5m survey intervals were used wherever practical, as shown in Table 21.

Table 21: Instrument settings and survey methods used at Drizzlecombe

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
Geoscan RM15	0.5m	0.5m	Zig-Zag (but preserving array geometry)	0.5 ohm resolution.
Geoscan FM256	0.5m	0.25m	Parallel	0.1 nT resolution
Mala RAMAC 500 MHz	0.5m	0.02m	Zig-Zag	57ns Time window and 0.02m trace interval. Presumed velocity of 0.08m/ns
Geonics EM38B	1m and 0.5m	1m and 0.5m	Zig-Zag	Both inphase and quadrature responses logged, and surveys completed in both horizontal (0.5m intervals) and vertical (1m intervals) coil configurations.

Once collected and downloaded the data was processed in GEOPLOT and GPR-SLICE as appropriate. See Appendix A for a detailed log of the corrections and enhancements applied.

11.3.4 Results and interpretations

For the data plots, see Figures 11.46- 11.67. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the Grid pegs. The interpretation plots were then digitised from the rectified data plots.

Description

In general, aside from problems with drift in the EM surveys, the techniques all produced results with some variation in response. Those responses were of very low magnitude, making genuine anomalies very difficult to distinguish from background changes and survey or instrument noise.

RM15 resistivity survey- Figure 11.46

The resistivity survey initially had a high range, from 314-1470 ohms; but this was largely due to strong spiking apparently caused by poor probe contacts. Once the data was corrected, the range narrowed to 372-607 ohms. This is higher than perhaps might be expected for a saturated, peaty soil, but the array dimensions mean that about $0.5m^3$ directly below the array is measured: on this site the soil is likely to be fairly thin overlying a resistive matrix of decayed granite. Prior to the High Pass Filter being applied (see Appendix A) a gradual change from high to low resistance was evident running from Grid 1, downslope into Grid 2. This trend overwhelmed any more localised variation, so the filter was applied to remove this gradient.

The high pass filtered survey results show a scattering of discrete (up to about2.5m diameter), relatively strong high resistance 'patches' in Grid 1 (20-30 ohms higher than the immediate area) with some larger, less intense and less well defined in Grid 2 (15-20 ohms higher than the immediate area).

There are some generalised areas of lower resistance (3-6ohms lower than the immediate area) that form elongated thin shapes, running (generally) in the direction of the slope.

FM36 Gradiometer Survey- Figure 11.47

 Before any corrections took place (including grid matching) the range of the data was from -6.68 to +11.32 nT; once the data had been corrected and despiked, the range

narrowed to -6.9 to 5.5 nT, which is fairly low. This was not unexpected, given the low thermoremnant magnetism of the Dartmoor Granite parent, the lack of settlement activity in the immediate area surveyed, and the inhibition of magnetic enhancement by waterlogging observed in peat soils (Thompson & Oldfield 1986). This created a very low signal: noise ratio in the survey, and this combined with difficult operating conditions (high winds, knee high hummocks) meant that parts of the survey are quite noisy and hard to interpret as small changes in instrument height and orientation that would normally be drowned out in the greater variations produced by features are instead the most visible effects in the survey. Nevertheless it is possible to identify a few discrete positive anomalies, especially in the north eastern part of Grid 1. These are, at their largest about 2m across and are only 1-2 nT greater than their immediate vicinity.

There is also a very diffuse zone of small, positive readings or positive 'noise' in Grid 2, elongated along the line of the slope.

There were no obvious dipoles or other strong magnetic anomalies and there is no evidence for modern ferrous material affecting the site.

EM38 Survey

The EM survey results were also narrow in range, which served to amplify the effects of instrument drift on the plots of the results. Given the depth of maximum response with the coils in vertical orientation, (0.3m-0.5m) it is understandable that these surveys produced no archaeologically or geologically interesting anomalies. These surveys were also conducted at 1m x 1m reading intervals, which may have been too coarse to pick up small anomalies. The horizontal coil orientation is most sensitive just below the ground surface, within the top 0.2m and in this situation seems to have produced a more useful response. This survey was conducted at 0.5m x 0.5m intervals, which again seems to be more optimal for the scale of the expected archaeology. No interpretation plots are included for the vertical coil orientation surveys as the results were, in archaeological terms, fairly uniform.

Horizontal Quadrature phase response- Figure 11.48

The Quadrature phase data shows a limited range: 1.5- 25 mS/m before correction and just 2.8-7.3 once drift and spiking had been taken account of. As discussed above, this low signal to noise ratio makes it very hard to distinguish archaeologically interesting anomalies from the background soil and instrument noise. The response did show some discrete areas of increased conductivity in the north east side of Grid 1; none of these are larger than 2m across and are less than 1mS/m more conductive than their immediate surroundings.

More diffuse but slightly stronger high conductivity zones were present along much of the southern long axis of the surveyed area. There was also a diffuse but relatively intense area of raised conductivity running roughly north-south for about 10m in the middle of the southwestern edge of Grid 2, and a smaller less intense patch along the western part of the north-west edge of the same grid.

Even taking account of drift and problems edge matching the grids, there does seem to be a trend towards lower conductivity readings in the middle of the survey area; readings in the middle third of the area were about 1.5 mS/m lower than the mean for the survey as a whole.

Horizontal Inphase response – Figure 11.49

The Inphase response was also a very narrow response, with values ranging from about -0.6-+1.2 ppt around a supposed background zero. There was little variability in the result which made teasing out any patterns very difficult. There was one reasonably straight-forward anomaly; a discrete area of increased response, about 2m across in the northern corner of Grid 1. In the greyscale plot of the data, no further anomalies were visible. When examining the trace plot, there were two faint linear trends of slightly increased readings, running diagonally across the traverses (and so unlikely to be processing or survey artefacts); these are tentatively plotted in Figure 11.74, but their identification is highly uncertain.

Vertical Quadrature phase response- Figure 11.50

The raw data ranged from -1- +4 mS/m, and after correction from +1- +4 mS/m. No anomalies of archaeological or geological interest were detected.

Vertical Inphase response – Figure 11.51

The raw data ranged from -0.1- +0.3ppt around a supposed background of zero. The corrected data ranged from +0.04- +0.2 ppt. No anomalies of archaeological or geological interest were detected.

GPR 500 MHz Survey- Figures 11.52 to Figure 11.67

The radar timeslices were examined as a whole dataset, and are described as such below. Figure 11.54 gives the estimated depths for each slice.

The radar survey produced a number of anomalies, over different depths. In the upper slices (2-6, 0.05-0.32m) there were a number of small (1m or less across) discrete strong reflections, particularly in the northeastern half of Grid 1. One or two of these in the centre of the group enlarge with depth (slices 4-6, 0.16-0.32m), but at no point form any clearly archaeological feature. There is a zone of scattered high amplitude responses from slice 8-12 (0.38-0.65m) in the south eastern half of Grid 2. This is interesting as it seems to have a definite end at 0.65m, rather than continuing to enlarge with depth as an outcropping from the parent rock might be expected to. There is a further anomaly, at greater depth here that might be a geological outcropping that appears from slice 18 (0.92m) to the base of the survey. There are also two clear, parallel lines of high amplitude response from slice 7/8 to 10 (0.32-0.54m), about 2m apart but perhaps getting further apart with depth. These run from just south of the middle of the southwestern edge of Grid 2, roughly north, for about 20m. There are also two high amplitude anomalies from slice 6 to 7 (0.27-0.38m), the first in the northern corner of Grid 2 and the second towards the northern corner of Grid 1. They appear to be concentrations of smaller high amplitude reflections; again these are interesting as they cease before the base of the survey, implying they are not geological outcroppings.

Interpretation

RM15 resistivity survey- Figure 11.68

Nothing in the resistivity data indicates a buried row of stones, or the pits or sockets that would be left behind if the stones had been removed at some point. The discrete high resistance anomalies seem in some cases to correspond with stone visible on the

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surface, indicating either a geological outcropping or a boulder, perhaps dislodged from the cairn immediately upslope of this part of the grid: the absence of similar anomalies elsewhere in the survey favours this latter explanation. The other responses seem to be geological, or at least soil-hydrology related; the downslope direction and diffuse but slightly dendrite form of the lower resistance readings suggest part of the soil with a greater through-flow of water as it moves downslope. The smaller low and corresponding high resistance zone are probably related to the footpath/ animal track that runs along the same line. Though the soil becomes compacted by repeated use of the track, the vegetation is also different and seems to allow more moisture to be present in the soil. The other areas of higher resistance noted seem more related to surface vegetation (and in particular heather and *molinia*) than subsurface features.

FM36- Figure 11.69

Though some discrete positive anomalies were noted, they were not strong enough to be likely to be anthropogenic in origin and probably reflect either slightly naturally enhanced area of the soil only visible due to the very narrow range of responses. The more diffuse zone of slightly elevated readings in Grid 2 might be an artefact of the data collection, but it loosely corresponds to an area immediately below the low resistance anomaly suggested to be hydrological in origin; it is also possible that this zone of the slope has become naturally slightly enhanced by the deposition of more silts and mineral content as groundwater passes through the peat soils; there is a settlement upslope of the site.

EM38 Survey
Horizontal Quadrature phase response- Figure 11.70

Very few of the anomalies identified seem to have a human explanation: the linear zone of higher conductivity seems to correspond to a footpath, and a low resistance anomaly discussed above. There seems also to be a zone of slightly raised conductivity associated with the extant, above ground stone row cutting across the southern corner of Grid 2. This would indicate higher moisture content in the stone sockets and surrounding disturbed soil profile. This was not reflected in the resistivity survey, but this is likely to be due to the difference in depth of maximum sensitivity between the two techniques. Given the narrow range of values, the other anomalies

are interpreted as being localised differences in soil moisture, more likely to be caused by different vegetation cover than the presence of pits, sockets or buried stones.

Horizontal Inphase response- Figure 11.71

The small discrete enhanced MS response in Grid 1 does not correspond to anomalies in any of the other results, so is unlikely to be caused by an enhanced fill in an archaeological feature. Given the slightly 'chaotic' nature of the anomaly (a series of small spikes mixed with lower than average readings), it seems more likely that there was a modern metal (and magnetically susceptible, but not magnetic) object on the surface.

The apparent linear enhanced features in Grid 2 were only very tentatively identified in the survey data. Again, these anomalies do not coincide with any anomalies of the same form in any of the other surveys. It is likely that they have been caused by a slight compaction (and so higher apparent MS, as this measurement is both mass and volume specific) of the soils in the vicinity of human/animal paths shown in the interpretation plot, or represent old paths no longer visible on the surface.

Vertical Inphase and Quadrature phase response

The lack of any variation in the survey is interpreted as the maximum sensitivity of the instrument being at a depth likely to be below the soil on the site, and within the relatively homogenous decayed granite subsurface. The greater survey interval also means that smaller scale changes would be missed.

GPR 500 MHz Survey- Figure 11.72

The scatter of higher amplitude responses in Grid one in the upper part of the survey is interpreted as being from smaller stones in the soil matrix, possibly tumbled from the cairn. Those that coalesce into larger groups of reflections over depth seem likely to be larger pieces of granite that have decayed *in situ*, producing the somewhat scattered response. It cannot be ruled out, however, that some of these may represent small cairns or cists that have become buried in the peat soil over time. None of them have particularly diagnostic forms, but there are so many in the immediate area this explanation should not be ignored. The parallel linear anomaly is interpreted as being

caused by compaction, possibly by vehicles, or previous footpaths on the site. It is unlikely to be a leat as it runs at 90 degrees to the contours.

The large diffuse zone of high amplitude 'noise' is unlikely to be a granite outcropping as it does not go to the base of the survey. It has no apparent structure though, and thus is interpreted as being an area where the soil and underlying substrate is stonier than the rest of the survey area. Its proximity to the stone row is interesting; but it is impossible to establish any causal links between them.

11.3.5 Case-study specific conclusions

The surveys have not identified any anomalies consistent with either a buried stone row, or sockets or robbers pits associated with one that has been removed from the site. This would seem at first to be a very straightforward conclusion, but the extant stone row that crosses Grid 2 also produced no anomalies that would belie its presence if you looked at the plots without knowing it was there. The grid layout was designed to cover part of the known row for this very reason; to provide a 'signature' or comparison, to look for in the rest of the data. It seems that the standing row stones did not disturb their immediate vicinity enough to produce a geophysical anomaly, apart from perhaps a slight general increase in the conductivity in the top 20cm of the soil. Logic suggests that this is in part because the stones are generally small, and due to the issues of surveying around them, were not directly surveyed; whereas buried stones are likely to be recumbent (and so giving a larger target), and the instrument can pass/ probe directly above them, meaning buried stones, or even their empty sockets should be easier to detect.

Negative conclusions are much harder to prove in geophysics as while you can be sure something has been detected, it is very difficult to know (without ground-truthing) if there was genuinely nothing to detect, or if your survey was incapable of detecting what is in fact present. Absence of evidence is not evidence of absence. However, on balance, despite the lack of response to the known archaeology, the data in no way suggests the presence of a row of stones running downslope from the cairn.

This agrees with the most recent phasing of the site (National Monuments Record 2000, 24104), which suggests that the cairns were built after the stone rows, rather

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than the rows being enhancements to them; the cairn does not 'have' a row because it was constructed after the rows and perhaps is located in reference to the other two that share that contour line on the slope, at the head of rows. This is backed up when the oft- cited 'terminal stone' for this 'planned' row is examined; in size and form it is much more like one of the smaller row stones than the other massive terminals found on site, and so is much more likely an isolated orthostat, or part of a different and undocumented monument (see Figures 11.73).

Ground-truthing a negative result is difficult; there are no targets suggested by the survey data so any excavation based solution would have to reply on either large open area excavation, or a programme of test pits or trial trenches. The risk of the trial trenching approach is that significant archaeology might be missed, thus falsely confirming the negative conclusion (Hargrave, 2006). Large open area excavations were inappropriate for this sensitive, scheduled site as they would likely result in erosion and the loss of known and protected archaeology. Trial trenching is not the best solution, and was both impractical and potentially damaging to the known archaeology on the site, so ground truthing was not followed up. If the surveys had produced any viable geophysical targets, limited excavations would have been useful, as at Yellowmead and Canada Farm, to check the interpretations.

11.4 Evaluation of techniques

The sites on Dartmoor produced quite different results, probably as a result of the absence of features at Drizzlecombe. As with the lowland sites, the importance of employing more than one technique is emphasised to allow cross confirmation of interpretations. Foreknowledge of the environment is important when considering resistivity array dimensions, GPR frequency, EM coil orientation, and whether or not to employ magnetometry. Care needs to be taken to match survey intervals and array dimensions/antennae to the archaeological target. Given the shallow conductive soils on these two sites, further research would be useful on the response of different resistivity arrays. The soil conditions have also shown that a 0.5m twin probe array can be directionally sensitive in the right (or wrong?) circumstances. This needs to be born in mind on future surveys. On the two sites surveyed, gradiometry proved to be the least useful technique, but this may not be the case on settlement or industrial sites where some MS enhancement might reasonably be expected. GPR generally worked

well, but care must be taken in interpreting strong reflectors as rock or stones, as lenses of other material might be causing the response. The ground-truthing work at Yellowmead also highlighted the impact human activity has had on the soil development, with implications for landscapes all over Dartmoor, and similar upland areas.

Chapter 12: Carn Meini, Pembrokeshire

The Carn Meini outcroppings of dolerite in the Preseli Hills in Pembrokeshire are an upland peat landscape with a high archaeological significance. They are the source material for the bluestones at Stonehenge, and also have a lot of archaeological sites of their own. They also appear to have been a source for polished stone axes. The landscape is being studied by the SPACES project (Darvill & Wainwright 2002; Darvill *et al.* 2003; Darvill *at al.* 2004; Darvill *et al.* 2005, Darvill *et al.* 2009) which has located a number previously unknown ritual sites in the landscape, including the first causewayed enclosure discovered in Wales.

The Carn Meini outcroppings are home to a number of spectacular well-known sites as well, such as the fortified hilltop enclosure of Foel Drygarn, with its massive cairns, and the stone circle at Bedd Arthur (see Figure 12.1). The two sites chosen were already known to archaeology, rather than new sites located by SPACES, but the geophysical surveys formed part of the SPACES research project, and so will be included in the reporting of it.

12.1 Llach-y-Flaiddast

12.1.1 Site background

Llach-y-Flaiddast is a chambered cairn (probably a simple passage grave) on the main outcrop, Carn Menyn, where the SPACES project has identified a number of enclosures, quarrying sites, and enhancements and rock carvings at spring heads. The cairn is large, around 10m in diameter, with an impressive capstone, and lies at the head of a spectacular natural feature: a 'stone river' that flows down the hillside from the outcropping. This feature was formed at the end of the last glaciation when the sudden melting of remnant ice clinging to the outcrop transported massive amounts of stone down its run-off route. The result is astonishing and it is easy to see that this place could become regarded as special in some way by people in the past, as has been suggested by Bradley (2000).

There are a number of apparently later structures, to the north and east of the cairn created from the stones of the cairn, and using parts of its structure. These have been

interpreted as sheepfolds or shelters constructed by shepherds, but none of them have been dated, see Figure 12.2.

There are thin, waterlogged peat soils with active though-flow of water from springs around the igneous outcropping, encouraging the growth of mosses (including sphagnum) in the wetter areas, heather, grasses, and rushes. The site is open grazing for sheep and has never been cultivated, being too steep for agriculture or peat cutting.

12.1.2 Survey aims

The specific aims of the survey were to investigate the area immediately surrounding the cairn for any evidence of an enclosing ditch, or other features now buried by the peat soils.

12.1.3 Methods and instrument settings

Surveys were conducted from 8-11 May 2007. The period immediately preceding the surveys was dry, but from the 9 May it was very wet and windy and remained so for the duration of the work.

Four 20m x 20m grids were laid out, making a 40m x 40m survey area, centred on the capstone of the cairn and roughly oriented to the national grid. The nature of the terrain and archaeology (bare rock over a lot of the site) meant there were gaps in the survey, particularly the resistivity and radar. Less than half of the total grid was surveyed by radar due to these difficulties with the terrain and time constraints.

Table 22: Instruments used at Llach-y-Flaiddast

Survey type	Instrument	Accessories/notes
Resistivity	Geoscan Research RM15(A)	0.5m twin probe array
Magnetometry (gradiometer)	Geoscan Research FM36	Manual trigger used due to incredibly rough terrain.
Electro-Magnetic	Geonics EM38B	Vertical dipole coil configuration. Both inphase and quadrature components of the response logged.
Ground Penetrating Radar	Mala RAMAC GPR	500 MHz antenna, 100 MHz survey wheel used to measure distances.

Table 23: Instrument setting and survey methods used at Llach-y-Flaiddast

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
Geoscan RM15	1m	1m	Zig-Zag	0.5 ohm resolution.
Geoscan FM256	1m	1m	Parallel	0.1 nT resolution
Mala RAMAC 500 MHz	0.5m	0.01m	Parallel	52ns Time window and 0.01m trace interval, 512 samples/trace. Presumed velocity of 0.08m/ns
Geonics EM38B	1m	1m	Zig-Zag	Both inphase and quadrature responses logged.

Once collected and downloaded the data was processed in GEOPLOT and GPR-SLICE as appropriate. See Appendix A for a detailed log of the corrections and enhancements applied.

12.1.4 Results and interpretations

For the data plots see Figures 12.3 to 12.22. The data plots were created as described in Appendix A and then exported to ArcGIS and rectified to the dGPS survey of the grid pegs. The interpretation plots were then digitised from the rectified data plots.

Results

Resistivity- Figure 12.3

A very wide range of readings were observed, due to the very thin topsoil and proximity of the geological parent. Furthermore, this survey was done before the wet

weather started so it is possible the surface had dried out. Results are inconclusive. There is a low resistance area to the south-east of the cairn and very high resistance zones correspond to the debris spread from the cairn itself and the stone river. There do appear to be areas of lower resistance flanking the stone river. There diagonal trend of interspersed high and low resistance anomalies in Grid 2 (running from s/e to n/w).

Gradiometry- Figure 12.4

The gradiometer data is curiously 'noisy' with high peaks that do not seem to be due to the presence of ferrous material in the topsoil. It is possible given the geology that some of the stones of the cairn and the stone river are more thermoremnantly magnetic than the general background and so are the source of these spikes. It is also possible, due to the highly varied topography, that some of the anomalies are due to the presence of rocks above/around the upper sensor of the magnetometer, as occurred when surveying within the stone river dip and upon the cairn itself. There does seem to be some correlation between some of the magnetically disturbed areas and the areas of some of the secondary structures, on the eastern and northern edge of the cairn. There are also some weak anomalies to the south west of the surveyed area that are potentially archaeological in nature, and correspond to a flatter area in the topography.

Vertical EM Inphase- Figure 12.5

The inphase response from the electromagnetic survey shows some higher than background zones of magnetic susceptibility, mainly to the east and north of the cairn and again corresponding to areas subsequently modified.

Vertical EM Quadrature- Figure 12.6

The quadrature phase response from the electromagnetic survey shows very little variation in the conductivity across the site, with a slight increase within the dip of the stone river and the suggestion of a rise then a drop along the northern edge of the cairn. There is a slightly lower conductivity zone at the eastern edge of the cairn, but this is barely different from the background. Again there are a few 'spikes' in the data possibly caused by the rough terrain or particularly heat-changed rocks.

GPR- Figures 12.7 to 12.22

The data was timesliced for assessment, and the estimated depths of the slices are shown in figure 12.7, and the timeslices follow as figures 12.8 to 12.22.

The technique does seem to have been effective, and in some areas dipping surfaces are present in roughly contiguous position to the purported ditch. However, the large numbers of boulders and rocks, within the area of the supposed ditch has meant that this dipping surface is difficult to discern in some profiles, or absent altogether and even harder to establish any kind of linear/annular trend for.

Slicing of the data has been undertaken, and there are no obvious archaeological anomalies showing.

Interpretations

RM15 resistivity survey- Figure 12.23

The strong contrasts on the site limited the interpretation, and were caused by the highly conductive nature of the wet soils in contrast with the resistive rocks present at and immediately below the surface. A number of low resistance features were identified, but their location and character appear more geological than archaeological, with no clearly anthropogenic origin. Given the lack of comparison sites, this interpretation should be tested by excavation.

FM36 gradiometry survey- Figure 12.24

The gradiometer results were almost completely swamped by noise and spiking caused by the igneous geology of the site, and the immediate topography, which meant stones were often close to the upper sensor, affecting the results. Tentative positive anomalies that may be of archaeological interest were identified on a flatter part of the site to the southwest of the cairn. Disturbed responses associated with the later structures added to the cairn may be indicative of occupation, though they could also be a result of the geology.

Vertical EM Inphase survey- Figure 12.25

The slight enhancement associated with the later structures added to the cairn would perhaps indicate use by humans as opposed to livestock. However, caution should be exercised over the interpretation as this area of enhancement is in the same zone as

the magnetic disturbance noted within the gradiometer data, and so could be a function of highly variable local geology.

Vertical EM Quadrature survey (not illustrated)

No potentially archaeological anomalies were located using this technique; the slight changes in the response seem to reflect the topography and geology of the site.

500 MHz GPR survey Figure 12.26

Some of the radar profiles show dipping surfaces in the area thought to be a ditch, but they are patchy and do not resolve into an overall feature. At best, it seems the ditch could be filled with stones, leading to a confusing response. There are some clear geological responses, such as the diagonal line visible in the northwest of the surveyed area, which is due to the slope change as the surface dips into the stone river.

12.1.5 Case-study specific conclusions

This site was not very well suited to geophysical survey. The topography and geology posed significant challenges. The most archaeologically useful information was provided by the EM inphase survey, which showed potential MS enhancements in the structures around the cairn, highlighting them as good targets for future excavations. The resistivity survey was low resolution, and used a 0.5m twin probe array, and so was unable to resolve any archaeological features. As concluded for Dartmoor (Section 11.5), exploring different array types for these shallow conductive soils needs to be a research priority. The GPR survey was beset by instrument problems, but showed potential, and so a re-survey of the site is planned as part of the SPACES project, building on the lessons learned during this piece of research.

The surveys have shown there are features that could be interpreted as a ditch, but nothing conclusive; ground-truthing is needed.

12.2 Croesmihangel

12.2.1 Site background

Immediately south of Foel Drygarn and west of the Carn Menyn outcrop, on an east facing slope, a Bronze Age cairn was discovered in the 1950s when it became eroded by livestock and Bronze Age urns had eroded out of a hollow in the soil. The site was partially excavated, in quadrants, and revealed some stakeholes, localised burning, a spread of quartz pebbles, and a number of funerary urns (Nye *et al.* 1983). During the work at Carn Menyn there was an opportunity to conduct a gradiometer survey of this site, but due to time constraints only this rapid technique was able to be applied.

In the 1950s, and now, the monument is barely visible in the topography of the site and the downslope side of it has been badly eroded by loss of topsoils and the action of livestock rubbing up against hollows to shelter from the weather. The southwest quadrant is mostly eroded away, and the northeast and southeast quadrants were excavated, leaving a baulk between them which is all that really remains visible of the monument in the topography.

The site is currently used as pasture, and consists of thin peaty soils over a gravelly/ sandy weathering product of the igneous geology. A number of springs emerge upslope of the site, and the water from these has contributed to the erosion (see Figure 12.27).

12.2.2 Survey aims

The aims of the survey were to locate geophysically the former excavations (the possible baulk of one of the quadrants was visible as an earthwork), to establish the immediate surroundings of the monument, and see if any features in the unexcavated parts could be detected.

12.2.3 Methods and instrument settings

The survey was conducted on 10 May 2007 during a period of very wet weather. The preceding few days had been very wet and windy, but the two weeks leading up to this period had been dry.

Four 20m x 20m grids were set up using the presumed old excavation baulk to align them over the centre of the monument. The two western grids were surveyed in full, but the two eastern grids were only partially surveyed due to very rough ground conditions (the aforementioned erosion) and a field boundary.

Table 24: Instrument used at Croesmihangel

Survey type	Instrument	Accessories/notes
Magnetometry (gradiometer)	Geoscan Research FM36	Manual trigger used due to incredibly rough terrain.

Table 25: Instrument settings and survey methods used at Croesmihangel

Instrument	Traverse interval	Measurement interval	Traverse method	Other settings
Geoscan FM256	0.5m	0.25	Zig-Zag	0.1 nT resolution

Once collected and downloaded the data was processed in GEOPLOT. See Appendix A for a detailed log of the corrections and enhancements applied.

12.2.4 Results and interpretations

For the data plots see Figure 12.29. The data plots were created as described in Appendix A and compared carefully with a plan of the excavation interpretation from the 1950s dig (see Figure 12.28); the spatial accuracy is limited here as we do not have precise location records for the excavations, so there is no GIS interpretation plot here, instead, an annotated data plot is provided showing anomalies of interest, as Figure 12.30.

The results clearly show the limits of the excavations as an area of disturbed signals. The excavations discovered four funerary urns with cremation deposits, one in a cist structure, and also showed stake holes and some evidence of structures within the cairn mound (Nye *et al.* 1983). The geophysical survey revealed a positive magnetic anomaly within the unexcavated area, near to the centre of the cairn and where some of the urns were found. This enhancement is unlikely to indicate a buried urn as they do not normally produce strong enough anomalies, but it could indicate an area of burning in-situ or a concentration of heat-treated objects. The excavations found

several deposits of charcoal. There was also a faint anomalous response at the north east edge of the area surveyed that could be related to a supposed ditch (Nye *et al.* 1983) around the cairn, though it is further out than the ditch located in the excavations.

12.2.5 Case-study site specific conclusions

Gradiometry proved to be a rapid tool to assess the remains of this Bronze Age barrow, and gave a clear indication of the former excavations and anomalies of potential archaeological interest. Away from the dolerite outcrops and stone-fields, the instrument performed well in terms of signal to noise ratio. The limited interpretation made of the site underlines the importance of using more than one technique wherever possible to explore as many properties of the sub-surface as possible, and to allow cross-checking of interpretations.

12.3 Evaluation of techniques

Gradiometer survey is clearly contra-indicated for surveys around these outcrops given the noise from thermoremnance and having boulders near the upper sensor affecting the background readings. However, on the lower slopes, where the ground is smoother and any rock is largely homogenous and buried, the technique seems to have responded well, locating former archaeological excavations and possible anomalies of interest in the unexcavated sections of the barrow. The resistivity results were very hard to interpret; this seems to be due to the thin, conductive nature of the soil and its saturation. This highlights the need for research into suitable alternatives to the 0.5m twin probe array for upland blanket bog environments. Though only a small area was covered, the GPR results proved relatively informative, especially in conjunction with the EM surveys. The EM surveys at Llach y Flaiddast were very useful, and comparatively straightforward to conduct on the difficult terrain.

Section Five: Discussion and conclusion

This section contains chapters 13 and 14, and concludes the research project.

Chapter 13 re-examines chapters 1-4 in the light of the case studies and laboratory work, discusses the results of the research project as a whole and brings together the key arguments about how archaeological geophysical surveys in these environments have proceeded in the past, and how that might need to change in the future.

Chapter 14 builds gives a critical resume of the results of the project, against the objectives set out in Section 1. Each of the questions raised in Chapter 1 is then considered, with a conclusion provided. It then goes on to describe the suggested 'toolkit' of techniques and practices for archaeological geophysical survey in peatland environments. Finally, it outlines priority areas for future research.

Chapter 13- Discussion

13.1 Introduction

This discussion chapter examines the main themes and concepts arrived at in peatland archaeology in general, and then more specifically in terms of geophysical prospection, referring back to section 1 of this document. It then goes on to consider how the eight case study sites fit into the existing body of work, and what new questions and challenges they have posed, building on the previous section.

13.2 Themes emerging from the literature

It is clear from the literature examined in section 1 that there has been a transition in the way archaeologists are thinking and writing about wetlands, and by extension, peatlands. This shift has been occurred over the last twenty years, and was built on an impressive tradition of wetland archaeology in the UK since Clark's work at the Mesolithic site of Star Carr. This change has several components, in part linked to the type of archaeology being done, and in part to do with movement in the wider discipline towards greater specialism. This can be demonstrated by a consideration of the four large scale wetland archaeology projects that occurred with the support of English Heritage from 1973- 2000; the Somerset Levels Project, The Fenland Survey, The North West Wetlands Survey and the Humber Wetlands Project. Table 26 below summarises the character and duration of each project.

Table 26: Summary of Wetland Research Projects in the UK, synthesised from Van de Noort (2002b)

Project	Dates	Techniques routinely used	Emphasis
The Somerset Levels Project	1973-1989	Fieldwalking, dyke survey, excavation, palaeoenvironmental research.	Rescue and palaeoenvironment
The Fenland Project	1982-1988	Fieldwalking, aerial photography analysis, palaeoenvironmental research, dyke survey	Rescue and characterisation; palaeoclimate work never properly integrated to archaeology (?)
The North-West Wetlands Survey	1998-1997	Palaeoenvironmental research, GIS, aerial photography analysis, historical data, fieldwalking	Integration, new mapping techniques, palaeoenvironmental research
The Humber Wetlands Project	1992-2001	Fieldwalking, geophysical survey, GIS, GPS, aerial photography analysis, excavation, palaeoenvironmental research	Integration, multi-specialist teams, GIS.

This clearly demonstrates several changes; the move from rescue archaeology to landscape scale research projects (which is a reflection of the changing threats to peatlands over time, rather than an indictment of the earlier projects), an increase in the number of specialised techniques employed by each project (reflecting increased specialisation and perhaps fragmentation in the discipline), with a concurrent emphasis on attempts to integrate all of this information (Van de Noort 2002b).

There is also an alteration in the interpretations of these landscapes on a number of conceptual levels. Early investigators assumed functional roles for many of the sites they encountered; trackways were for moving through or making use of the wet places they crossed, or were landing stages for watercraft; the platforms at Star Carr were a hunting camp (Van de Noort & O'Sullivan 2006, 48), and Flag Fen was being illustrated and described as a defended lake-settlement as recently as 1989 (Coles & Coles 1989, 138), though some ritual aspects of these sites were being recognised.

It is now widely recognised that these sites were, in the main, non-utilitarian structures; they were special places, with ritual functions, whether realised in the creation and renewal of them (as perhaps at Fiskerton (Field & Parker Pearson 2002)) or in the use they were put to; as places where wild landscapes were enculturated, or people communicated with their ancestors or the gods. This shift in perception extends to sites in Europe as well; even where practical uses of trackways is recognised there are interpretations that intertwine the ritual with the prosaic such as Corlea 1 in Ireland, which was clearly a practical structure, but had elements of ritual as well (Van de Noort & O'Sullivan 2006, 50-63). The focus of interpretation since the 1990s has been on the characteristics of the landscapes in which these sites exist, with notions of transience and liminality playing an important role. Wet places, or the boundaries between these places and the rest of the landscape, are seen as places where people's relationship with the landscape, each other, and perhaps their ancestors is made material (Bradley 1990; 1998; 2000; Van de Noort & O'Sullivan 2006).

Tied into this crucial concept is a point Van de Noort and O'Sullivan make very effectively (Van de Noort & O'Sullivan 2007, 80). The idea of a 'wetland' is a late

20th Century construction. People in the past, including the recent past who dwell within or alongside these landscapes did not think of them as 'wetlands' in the sense of a unified concept, but rather a series of different environments with distinct characteristics and cultural associations. This is well illustrated by etymological research about the names for different sub types of wetlands, and how these feed into place names in Northwestern Europe and the UK (Thier 2007). Van de Noort and O'Sullivan call for recognition of this in the discipline of wetland archaeology, and for more attention to be paid to the changes within a landscape over time, in terms of settlement, subsistence and ritual activity, and within the palaeoenvironment. This approach is employed to good effect in a study of changing perceptions of the Humber wetlands in the Bronze Age (Van de Noort 2002a). Whilst there are excellent examples of well integrated palaeoenvironmental reconstructions (Coles & Coles 1986; French 2003a; b), the issue operates on a more theoretical level, and the inherent assumption of a generalised landscape type of 'wetland' could cause problems of bias in terms of the types of investigation pursued and the research questions investigated.

This concept also challenges the assumption that all 'wetlands' were automatically rich resources, highly attractive to the communities that lived near them. There are large differences in biodiversity and biomass generation between different types of peatland, with blanket and raised bogs actually being relatively ecologically poor (Van de Noort & O'Sullivan 2006, 38-40). The assertion that human activity can be expected in all peat/wetland deposits (Olivier & Van de Noort 2002) is open to challenge. This is not to say that some peatlands are worthless; they still contain important palaeoenvironmental sequences, vital to understanding wider human effects on the landscape, but that we cannot expect to find all kinds of human activity represented under or within all kinds of peat. This growing recognition of the specificity of peatland environments is demonstrated the choice of Oxford Archaeology North (Quartermaine *et al.* 2007) to use a form of predictive modelling to suggest areas of high archaeological potential in their examination of upland peat.

There is a wider conceptual issue at stake here as well; in the heyday of the 'wetland revolution' wet archaeology had been hailed as a panacea for all that ailed prehistory; here we could directly access the lifeways of ancient peoples as we could recover so

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much more of their material economy that was possible on dryland sites. Theory was not necessary as you could read the past directly from the overwhelming quantity of evidence. Wet sites could be used to make inference back to dry sites, and fill in the gaps in our knowledge. This is now known to be manifestly not the case; wetland (and so peatland) environments were special places in prehistory, and remain special places now; we cannot assume sweeping continuities in cultural practices or even everyday life through the landscape. In all likelihood the artefacts recovered from these contexts are specific to them, not simply preserved here but not elsewhere. It is true that organic remains from dry sites are rare, and that prehistoric communities relied on organic materials a great deal, but we cannot assume that the finds from these sites are representative of whole cultures. We now understand wetlands as part of complex ritual and practical landscapes where everyday activities took place alongside religious ones.

13.3 Themes emerging from the geophysical literature

Classification has obvious implications for geophysical survey. It is complicated by the fact that geophysics must take account of the current geomorphology and pedology and intervening deposits as well as the deposits of interest, either within or below the peat on an old land surface. The environments represented may have been radically different, but need to be understood in order to correctly interpret the site. As demonstrated in section one, current terminology used in archaeology to differentiate non coastal wetland sites is very simplified, distinguishing between upland peat, lowland peat and alluviated wetlands. While the need for greater complexity in description of the types of environment that gave rise to the current peatland has been recognised by wetland archaeologists, it has been slow to filter out to the rest of the discipline.

Examining the geophysical surveys and their role within wider landscape studies, several themes emerge. The main problems with the use of geophysical prospection in these environments are issues of interpretation of results and consistency of responses. Either results are obtained, but are difficult or impossible to interpret apart from in a few specific circumstances, or features are not detected in situations which could be reasonably assumed to have been 'successful' on the basis of previous surveys; for example the failure of GPR to detect any features at Fiskterton (Linford, N 2003),

despite successful detection of timbers within waterlogged deposits over the Sweet Track (Utsi Electronics 2001) and at sites in Scotland (Utsi 2003).

Successful surveys have frequently been specific responses to the problems posed these environments, like the SIP applications (Schleifer *et al.* 2002; Weller *et al.* 2006), which rely not only on a specific monument type, but also the specific construction techniques and the depth of burial, or Challands (2003) method of prospection of MS levels on palaeosols buried in peat; only applicable on sites where you are expecting MS contrasts due to human activity and the subsequent waterlogging has not destroyed any contrasts. A serendipitous example of these highly specific applications is the EM survey of a French trackway by Tabbagh (1986) which located the trackway by proxy, using the conductivity responses from bronze hoards placed along its length.

Ground Penetrating Radar has been hailed by English Heritage (2008, 16-7) and Utsi (2007) as a possible solution to the problems in these environments, and has been employed with some success at Ballachulish (Clarke *et al.* 1999a; Utsi 2004), and other sites in Scotland over known trackways (Utsi 2003), in urban/ building contexts (see Table 1 in chapter 4), over the Sweet Track (Utsi Electronics 2001), and undated ditch, pit and kiln features at Stilton (see Table 1 in chapter 4). From the records available, the only survey confirmed by excavation following the radar survey was Ballachulish Moss (Clarke *et al.* 1999a), and there were some possible ambiguities in what was being detected there; it is possible the radar was responding to the sand and gravel of the platform, rather than the wood used in its construction. It is hard to determine, for the other surveys, if the results were ground-truthed. This is particularly the case for commercial surveys and is part of a wider problem of a lack of ground truthing feedback regarding geophysical surveys, especially in commercial circumstances, where the excavators are often a separate company to the surveyors (Jordan 2009).

Where sites have been ground-truthed, the information obtained has often altered the interpretation of the surveys, most demonstrably at Seamer Carr, where a number of promising kiln or hearth like anomalies were identified in the gradiometer survey, but on augering turned out to be natural concentrations of more ferrous material within

the soil (Haddon-Reece 1977a; c; d; b). The process by which these deposits were formed was not investigated at the time, but seems remarkably similar to the anomalies and iron mineral concentrations reported in the Dutch peri-marine landscape (Kattenberg & Aalbersberg 2004; Kattenberg 2008).

Geophysical survey is starting to be used in innovative ways in other environments, for example the work of Benech (2007), using gradiometer generated plans of Greek cities to conduct access analysis to interpret social interactions and the use of space within the city. This seems to reflect a trend moving geophysical survey in general away from site detection (though this is still a key application) to site interpretation, such as the work by English Heritage to use geophysical survey to examine processes occurring the ploughzone (Linford, N *et al.* 2007). Upland peat environments have also recently been reassessed on Dartmoor, where geophysical surveys have been employed as components in more general work, which has challenged Fleming's interpretation of the reaves as evidence for a planned Bronze Age enclosure of the moor (Fleming 1988; Johnston 2005).

Overall, the situation seems less pessimistic than the current survey guidelines for England would suggest (English Heritage 2008, 16-7), but there are issues. The key theme is variability, which ties into observations above about the need to be much more specific about these environments and their characteristics before surveys are designed and attempted. These environments are complex, but can seem to be unvarying from the surface. A key observation of the surveys recorded on peat in Chapter 4 was that the majority of them have been single-technique surveys. These have yielded results, but some of the more successful sites employed a combination of techniques, and given the complexities involved it seems more sensible to examine as many properties of the sub surface as possible, to avoid over-simplified impressions of the site being formed.

Given the conclusion reached Section 13.2 regarding the importance of landscape to the future of wetland archaeology, and the potential identified here and in Section 13.4 below, geophysical survey can potentially fulfil an important need. Advances in technology that have increased the speed of data collection and processing mean that geophysical survey is now a viable tool for approaching landscapes, rather than

specific sites (Kvamme 2003; Cheetham 2008). Geophysical survey has the potential to bridge the gap between the scales, and provide landscape contexts for wetland sites.

13.4 The new case studies and their contribution

 In geophysical terms, the case studies would seem to agree with the Sections above; these environments are complex, and present significant challenges to interpretation. Geophysical survey can make contributions to our understanding of these sites, particularly by contextualising them, both in a wider landscape, and, on deep-peat sites, within change over time. Furthermore, the case studies show the benefits of using multiple techniques, and the key role ground truthing has to play. Very few of the previous surveys in the UK has employed more than one technique to the same area of the site, making it hard to comparatively evaluate the results produced. There are also very few recorded uses of EM survey in these environments.

All of the geophysical surveys conducted as part of this project produced results which either showed some features of archaeological interest, or in the case of Drizzlecombe, produced a 'negative' result that fitted well with the interpretation of the site. However, there were very few straightforward interpretations of the results. The only anomalies that were consistently positively resolved by survey alone corresponded to already known features or surface conditions on the site and the features only visible in the surveys proved to very challenging to interpret.

13.4.1 The lowland surveys

The two areas at Flag Fen were particularly challenging. Area 1 had so many features, at different depths, and with so much modern activity, that without the ground truthing work it would have been very difficult to offer much of an interpretation. There was a jumble of activities from multiple periods. Modern features were associated with current or recent footpaths, reconstructed structures and old excavation trenches. There was some likely to be Medieval evidence, in the form of the enhanced area adjacent to the Roman causeway now interpreted as a ploughing headland, but originally suggested as a possible ditch. There was also the Roman causeway, but little that could be suggested to be prehistoric. There was also a large feature showing in the resistivity and GPR surveys that was the subject of intense

debate; only resolved when coring suggested it was made of similar material to the causeway and thus a possible offshoot. These features are notoriously hard to find on dry sites, as they present only ephemerally. Here in the peaty soils and alluvium, it stood out like a sore thumb, complicating the interpretation of it. Area 2 was a little less confused and produced clear evidence for superimposed agricultural landscapes in the upper parts of the soil profile, but little evidence for other feature types, particularly the hoped for prehistoric ones which are definitely known to be present in the area surveyed.

In some ways, Flag Fen could be seen to be the least successful of all of the case studies; none of the Bronze Age timbers were located by the surveys, and no anomalies that could be reasonably associated with this phase of the site were detected. However, it also most effectively demonstrated the potential for geophysical survey in these environments, exemplifying a number of my conclusions. The sediment sequence here is important to the success or failure of the surveys, and understanding the specifics of each survey area was vital to arriving at satisfactory interpretations of the data. It also shows how important it is to use techniques in combination; especially the use of the EM to corroborate interpretations made from gradiometer and resistivity data. This was particularly important in Area 1 where there were lenticular areas of enhancement that the gradiometer missed, and where other enhancement features were confirmed by this method. It also gives a different perspective on the archaeological landscape at Flag Fen, especially the discovery of the narrow cord-rig style ploughing buried below a later field system. There is a large landscape on this site that lies somewhere above the Bronze Age timbers, and around 0.7m to 0.9m below the current topsoil, and there is strong potential for that to be prehistoric. Previous investigations on the site have quite rightly focused on the Bronze Age levels and the waterlogged deposits, though possible evidence for a similar type of agriculture exists elsewhere in the environment, and has been identified in geoarchaeological studies in the lower Nene Valley (specifically the area between Second and Third Drove roads (French 2003b, 107). These intervening landscapes need further investigation and fitting into the palaeoenvironmental and palaeogeomorphological sequences established for the area. The two case studies here also demonstrated that ground truthing in these environments can be simple, inexpensive and relatively rapid. A day of coring along with some simple laboratory

tests of MS, MC and LOI allowed some interpretations to either be disregarded or proven, and some of these decisions were possible while in the field working on site.

Even where the features matched the expected archaeology at the Canada Farm site on the Sweet Track surveys, the relationship between the geophysical anomalies and the archaeology was complicated and, apart from the GPR, likely to be indirect. The subsequent ground truthing investigations, including the chemical analysis, gave conclusive answers. Variations detected in the chemical distributions of key elements within the peat correspond with the geophysical anomalies and trends identified on the site. There is a growing body of literature using multi-element chemical analysis to examine archaeological sites, though usually either in high resolution small scale surveys to determine the use of a particular feature or building, or at wider densities as a form of site prospection. Chemical tests have also been used to look at conservation implications at Star Carr. What is clear from this project, the work on other types of site, and a review of the literature (covered in Section 1) is that peat chemistry and hydrology are still developing sciences. The intersection between them, and then between this and the response of geophysical instrumentation is just starting to be explored. More work is needed in this important area, as it is possible the hypothesised situation on this site is not unique, and these intersections of chemistry and physics might be exploited by surveyors, if they can be adequately predicted. The Old Peat Works site produced very ambiguous results, with a few anomalies that are possibly archaeological and linked to ephemeral occupation or use of the higher ground. The peat in this area was desiccated; it is used as pasture land and has not been re-flooded, unlike the Canada Farm area. It is possible that the trackway lay outside of the survey area, or did not survive in the dried peat. It seems more likely that this was the case, rather than the desiccation of the peat itself causing problems with the survey.

Overall, these surveys seem to agree with the previous body of work. Ground Penetrating Radar located the Sweet Track, and this was demonstrated with ground truthing. Utsi (Clarke *et al.* 1999a; Utsi Electronics 2001; Utsi 2003; 2004) has, in particular, shown that GPR could detect waterlogged wooden remains in peat and all of the successful sites were over raised bog deposits where there was still a high water- table. The chemical studies at Star Carr (Boreham *et al.* 2009) and as part of

the work carried out by Kattenberg and Aalbersberg in Holland (2004; 2008), as well as the observation of similar mineralization at Seamer Carr (Haddon-Reece 1977b) match well with our findings from the multi element analysis, but much more work needs to be done in this area. Magnetometry cannot however be discounted as it is a useful cross-check of interpretations, and on some sites the expected problems of reduction of magnetic contrast simply do not occur. This was evident, for example, in the Sutton Common surveys (Payne 2003), and at Flag Fen.

The themes in the lowlands revolve around specificity and the need to be able to resolve surveys in three dimensions.

13.4.2 The upland surveys

In the uplands, at Yellowmead, the seemingly straightforward interpretation of the bank and leat, and the anomalies associated with the circle's centre, especially in the radar and resistivity surveys was considerably altered by the ground truthing excavations. Initially it was assumed that the strong reflections were being produced by stones within the core of a bank, and that the 'inversion' of the resistivity anomalies produced was topographical. On excavation it was clear that there was no substantial stone in the bank, and that even with the covering of upcast natural, the peat soils protected within the core would produce a lower resistance response than the thin soils directly overlying the natural in the ditch. The surveys produced some curving anomalies in and around the circles, but the excavations showed these were not associated with ditches, and that the jumbled response high in the radar and in the resistivity was probably associated with a spread of material from an original central cairn. Human impacts on soil development caused by the leat were visible in the resistivity and GPR surveys, and confirmed by the ground-truthing work, which has implications for the survey, interpretation and management of similar sites on Dartmoor and elsewhere.

Drizzlecombe was challenging to interpret. The surveys on the whole did not have anomalies indicative of a stone row, but they also did not show any anomalies associated with a known and mapped stone row that crossed part of the survey area. As argued in Chapter 12, I consider that the results strongly suggest there is not a stone row associated with cairn A, but negative results are impossible to prove without total excavation, and it remains possible that there were features that were not

detected. With hindsight, these two upland Dartmoor sites would have been excellent places to trial a 0.25m twin probe or M-PET array (Cheetham 2001), with a smaller survey resolution in an attempt to gain more sensitivity in the crucial upper part of the soil profile, and detect smaller targets. Trialling of these methods in upland peat landscape is a recommendation for future research, as discussed below.

Ground truthing was not possible for the Preseli surveys. The Llach y Flaiddast results are likely to be tested at some point in the future of the SPACES project, and this will be very welcome; a number of ambiguous responses were detected, especially concerning the presence or absence of a ditch; low resistance anomalies were detected in a corresponding location, but it is possible this is a feature of local drainage. When compared with the surveys at Yellowmead and Drizzlecombe, the data here appears to be a lot noisier, or more strongly contrasted, much like the area below the leat. This could well be masking archaeological features as they are lost in the strong contrasts between the outcropping geology and the wet peaty soils. In this area, the igneous geology was problematic; due to both the nature of the rocks (fast cooled dolerite, as opposed to the slowly cooled granite that forms Dartmoor, leading to greater thermoremnant magnetism), and the position of the stone in relation to the upper sensor of the gradiometer. As a side note, this may also be what cause the odd gradiometer responses near the larger stones at Yellowmead; certainly some large stones at the Kes Tor and Shovel Down surveys seem to have caused anomalous responses (Johnston & Wickstead 2005). The Croesmihangel surveys clearly showed the former excavations (Nye *et al.* 1983), but other promising anomalies proved difficult to interpret, and with only one survey technique available there were no opportunities for cross-verification of the interpretation of small positive anomalies being potential further urns or cists.

The surveys in the uplands were, in general, more straightforward than the lowland ones. This may in part have been because the peat soils on the sites selected were not deep peat, being blanket bog rather than upland raised mires. In fact, the vegetation changes at Yellowmead associated with the stones, and the compaction of the soil, both caused by humans and animals being attracted to the site by the upstanding archaeology, mean that most of the soil horizons sampled were less than 40% organic,

although not by much. Even so, there were issues specific to each site creating ambiguity in the results, only adequately resolved with ground truthing.

However, despite problems with interpretation, the techniques that seemed to work best were radar and resistivity, though at Llach y Flaiddast the EM survey proved a useful cross check of this, and showed evidence for later habitation in some of the structures added to the cairn, and gradiometry worked well at Croesmihangel. This seems to be in line with other upland geophysical surveys, though they seem to be much less common than the lowland ones. As part of the upland peat project, resistivity and radar were used to survey sites at Angelzarke Moor, and the Forest of Bowland in Lancashire and Barnscar and Langdale in Cumbria, providing useful complimentary results with clear anomalies of archaeological interest (Quartermaine *et al.* 2007). On Dartmoor, the work at Shovel Down and Kes Tor (Johnston & Wickstead 2005) obtained useful results from resistivity survey, but also from magnetometry, picking up a possible kiln and other sub-surface features. At Langstone Moor (Dean 2003), a gradiometer survey produced useful information about a stone circle, despite problems with the presence of large amounts of modern military ordnance affecting the results. The main challenges that emerge from the literature and the case-studies centre on survey resolution, and being able to deal with the highly contrasted nature of the soil in terms of moisture levels, and the relative proximity of the geological parent in comparison with a lot of dry lowland sites with well developed soil sequences. Of course, in the deeper upland peat deposits, such as those to be found on the high moors of Dartmoor, the problems are going to be more similar to those encountered in lowland peat environments, though with less incidences of interleaving peat and alluvium.

13.4.3 Other observations

There are a number of observations that cover work in both of the 'environment types' identified at the start of the research project.

The most important is that the simple distinction between upland and lowland peat has been shown, by my own work, and by more recent debates in the literature (Van de Noort & O'Sullivan 2006; O'Sullivan & Van de Noort 2007; Van de Noort & O'Sullivan 2007) to be inadequate. The reasons for adopting such a classification for

this project were logical; it is the main classification used in the extant literature; alternatives have not yet been sufficiently developed, though the need for them is being recognised. Published strategy documents (Olivier & Van de Noort 2002; Van de Noort *et al.* 2002a; Hodgson *et al.* 2005) make extensive use of the upland/lowland/alluviated wetland classification scheme. This is in need of urgent revision. As a discipline we need to move away from blanket classifications that are a late 20th Century construct (Van de Noort 2002a; Van de Noort & O'Sullivan 2006; 2007) and start to explore the specificity of these environments, and of the archaeology they contain. We also need to challenge the assumption that all peatland landscapes in the past were important exploited economic resources; more recent consideration of the evidence has shown that at times in the past some wetlands/ peatlands were 'other' and unknown; dangerous or otherworldly places. This does not necessarily remove them from the economic cycle, but we have inherent assumptions built up over a long period that need to be undermined and questioned about how they were used and perceived by prehistoric groups. Geophysical survey is already playing a role in this; for example as already mentioned on Dartmoor where ideas about the Reaves and use of the high moor are being challenged. At Flag Fen the case study work showed potential prehistoric landscapes that were arable in nature, overlying the monuments and peat in soils that had seemingly been deliberately improved, or perhaps exploited following a silty alluviation event.

This brings us to an important and wider argument for wetland archaeology. In the heyday of large wetland research projects, 'wet' archaeology was being evangelised as panacea for interpreting prehistory (Coles 1987). The argument was that wetland sites offered so much more information about the past than dry sites that they could be used to make inferences across the whole of prehistory. We can now demonstrate that wetland sites are not now, and were not then, simple analogues of sites in other parts of the landscape. Careful examination of the sites, and the maturing of landscape theory in archaeology has shown us that these were special places, used in specific ways by different cultures and at different times (Bradley 2000; Field & Parker Pearson 2002; Van de Noort 2002a; Conneller 2004). They are more united in their non-utilitarian functions and place in society than by the insights they offer into quotidian existence.

With this in mind, I feel it is even more important to understand the immediate site context, to understand the relationship between the site and the landscape. This is more challenging in peatland than elsewhere because the original landscape is often buried, or at least somewhat altered from its topography at the time of monument construction. The environment is likely to have changed as well. Whilst peatland archaeology has consistently involved palaeoenvironmental reconstructions, there are issues of scale, with the immediate zone able to be reconstructed by the beetle/insect/snail and plant macro and microfossil remains, including diatoms. Pollen analysis can describe vegetation cover at varying scales, and geoarchaeological studies locate previous river channels, flooding episodes and erosional and depositional events. However, geophysical survey and in particular those techniques with a depth component can resolve the immediate landscape(s) associated with a site or findspot. In fact, they are in some ways better developed for these types of survey rather than the finer resolutions needed to detect features and finds (Jol & Smith 1995; Volkel *et al.* 2001; Slater & Reeve 2002; Leopold & Volkel 2003; Comas *et al.* 2004a). For example, at Ballachulish it became apparent that the platforms in the peat were located near 'headlands' of firmer ground that had since been engulfed in the peat (Utsi 2004). GPR is particularly useful in these circumstances as it has been shown to be good at detecting the original landform, and also differentiating layers of waterlogged sediment. It has been used in ecology and commercial peat assays for this purpose for decades. ERT also has useful applications. Geophysical surveys could usefully be teamed up with coring, pollen and other types of geomorphological and palaeoenvironmental studies to better reconstruct environments at the site level. Geophysical surveys to establish peat depth could be used to design coring transects, for example, and allow the deeper peat deposits to be targeted for pollen sampling. Admittedly, the case-study surveys were keyholes, in one sense, but they provided the right level of information for this particular piece of research.

The surveys that were ground-truthed showed that all surveys benefit from verification. Interpretations such as stones being present in the bank of the leat at Yellowmead were firm interpretations, but were overturned by ground truthing. It is clear that in these particular environments, ground truthing is required as often as is practically possible, at least until a sufficient body of work has been built up to allow inferences from one site to another. Given the earlier arguments about the specificity

of these sites and landscapes, it may well be that such inferences are never possible. Furthermore, the nature of the archaeology in these environments often makes interpretation difficult at the best of times; prehistoric sites tend not to have regular, diagnostic features like Roman villas or Medieval monasteries. Years of survey and ground truthing have allowed a reasonable picture to be built of what dry land prehistoric sites look like in geophysical data; informed in a large part by the much older practice of identifying monuments from crop and soil marks in aerial photographs. Wetland/peatland sites can be quite different, particularly when they were created in already wet conditions, and we have no history of aerial prospection for these sorts of features. Sites that were created on dry ground might be more likely to resemble other prehistoric monument types, and thus be more likely to be recognisable in survey plots. They have other advantages too. As shown at Sutton Common and Meare Lake 'Village' (Chapman & Van de Noort 2001) these types of site are created upon, or from minerogenic deposits, which have subsequently been engulfed in peat. Recent desiccation of the peat has created microtopographic (or even larger changes visible as earthwork-like) features which have been successfully mapped with dGPS survey. The possibilities for LIDAR prospection for these types of site need to be explored. Sites that were 'dry' when they were created are also more likely to respond in conventional ways to survey, unless the waterlogging has affected the MS signatures of human occupation, as Kattenberg has hypothesised for some Dutch sites (2008).

In situ preservation is the preferred method for wet archaeological sites where possible, as excavation and conservation processes are time consuming and expensive. However, preservation *in situ* can only work if the preservation conditions are maintained, which means sustaining the higher water-table, and avoiding acidification (Brunning 2007). Studies at Star Carr, for example, have shown a large increase in the acidity of the peat and groundwater, possibly caused by fluctuations in the water-table driving chemical changes (Boreham *et al.* 2009). Alarmingly, there is some suggestion that these changes are dissolving the antler artefacts the site is so rightly famous for. Desiccation *in situ* is as large a threat as peat extraction. In the Uplands, there are well documented problems with grazing regimes and encroaching plant species (Dartmoor Preservation Association 2008; Paxman & Turner 2008; Rendell 2009). Monitoring commonly consists, in the lowlands, of dip wells or piezometers to

examine changes in the water -height over time, and more recently reduction-oxidation potential (Eh or Redox) monitoring stations. pH and groundwater chemistry are also important to observe. As well as monitoring the burial environment, small scale excavations can be used to obtain samples to look at the condition of the archaeology itself, though assessing decay is complex, and the mechanisms by which it occurs are not fully understood (Brunning 2007,44-5). Geophysical survey has a potential role to play here. Environmental geophysics is already used for ground water modelling on landfill sites, for example, and in the detection of contaminated water plumes. Electrical survey methods are used in soil science to measure salinity (Lesch *et al.* 2004), and archaeologists are familiar with interpreting this sort of data. Geophysical surveys might also respond to chemical changes in the ground water, as observed at the Canada Farm site (see Chapter 9). If the relationships between chemistry, moisture levels and conductivity can be resolved for these environments, geophysical survey might be a relatively inexpensive first step monitoring tool. Certainly at Flag Fen, the site archaeologist and education officer Mike Webber's first question about the geophysical surveys there was 'can you tell us where it might be drying out?' (pers. com. Webber 2007).

Finally, the issues of site access and ease of survey need to be considered. Peatland sites are often hard to access due to their boggy nature, and in the uplands due as well to their remoteness and topography. This impacts on the efficiency of survey in terms of time taken to access and set up on site. They are also often very rough landscapes with hummocks and tall vegetation. This causes particular problems for both GPR and gradiometry, GPR because it is essential to maintain good ground coupling of the antennas, otherwise artefacts may be introduced in the data, or signal penetration lost (Conyers 2004). Gradiometry is impacted due to heading errors and uneven walking paces and gaits produced by the undulating terrain. This can be resolved to some extent by experienced surveyors and by using a manual trigger rather than a timed/pace based measurement, but again this has implications for the efficient use of what might be limited time on site. Surveying on slopes has its own problems of interpretation, but is also tough on the equipment, particularly the model of GPR used in these surveys, which was top heavy and prone to rolling down the slope, risking damage to the equipment and necessitating restarting survey transects. These landscapes also have challenging operating environments, combining wetness and

quite often (if you want to survey when there is no bracken growing) low temperatures, which has impacts on battery life, and the potential for moisture getting into the electronics on the instruments. These issues need to be planned for when surveying in peatlands.

Chapter 14: Conclusion

14.1. Introduction

Chapter 1 set out clear aims and objectives. The first part of this chapter will summarise the results of the project, considered against those objectives. The second part of this chapter will focus on the key questions that were distilled from the aim and objectives of this research project and will answer those questions in the frame of the projects case studies. A third section is devoted to answering the main aim of the research; guidelines for archaeological geophysical surveys in peatland environments.

Finally, suggestions for future research will be made.

14.2 Measuring success

In section one a set of outputs were specified as measurable outcomes of the above set of aims. This section deals with each of these outputs in turn and evaluates them.

14.2.1 Output A

a. A full and current analysis of archaeological geophysics, wetland/peatland archaeology, near surface environmental geophysics and peatland ecology and chemistry in the form of a literature review (objectives 1, 3-5)

This objective is realised in chapters 2-4 of this document, and discussed in chapter 13. It is important to conclude here that peatland chemistry, physics and ecology, and the intersections between them are not yet fully understood, particularly peat chemical processes.

14.2.2 Output B

b. A classification system for peatland environments specific to this frame of reference (objective 3)

A typology was developed for this research project, which allowed the selection of a representative set of case studies. On reviewing the results of those case studies, and the literature, a key conclusion of the research has been that the binary distinction used in archaeology between upland and lowland peat, which underpinned the

classification scheme developed for the project, is inadequately detailed to make the correct decision about survey strategy in these environments.

14.2.3 Output C

c. A classification of geophysical archaeological targets specific to this frame of reference (objective 5)

Generally speaking, the classification of sites as either 'above, within or below' the peat deposits was useful and successful. It does carry some inherent assumptions that should have been more fully explored and explained though. We might instead prefer to think about these sites as being after (above/supra) the formation of the peat deposit, laid down during bog conditions (within/intra) or laid down on subsequently inundated minerogenic soils (below/sub) the peat. This allows a more direct assessment of the sorts of archaeology likely to be encountered in these deposits.

14.2.4 Output D

d. A group of completed case studies that as a whole allow testing against all of the above classifications (objective 2)

Chapters 9-12 deal with this output. This projected has succeeded well against this key objective. Eight case study sites were studied in differing peatland environments, and where different types of archaeological site were expected. All of the surveys produced archaeologically useful conclusions, and were able to help resolve specific research questions developed for each site.

14.2.5 Output E

e. The reporting of those case studies to English Heritage, the Landowner, Local Historic Environment Record and the Archaeology Data Service (objectives 2, 6-8)

The case studies have all been reported, where appropriate to the local HER, to the English Heritage Geophysical Survey database and, again where appropriate to the AIP (Armstrong & Cheetham 2008a, 2008c, 2008e, 2009a, 2009b, 2009c; Armstrong 2009). Arrangements have been made for Plymouth City Museum to receive the site archive from Yellowmead Down. Aspects of this work have also been disseminated at

various conferences during the course of the research: (Armstrong 2008; Armstrong & Cheetham 2008b; 2008d; Armstrong *et al.* 2009). The work in Wales has been published in Archaeology in Wales (Darvill *et al.* 2009). There was also considerable interest from members of the public at some of the case study sites: Flag Fen is a visitors centre, so the aims and techniques of the research were explained to members of the public there. The work at Yellowmead Down was reported in local newsletters and journals (Armstrong 2009b, 2009c), and during the excavations members of the Dartmoor Preservation Association came on an organised site-tour. It is planned to lodge the digital data produced by this project with the Archaeology Data Service. Reports on the laboratory investigations of samples from Yellowmead and Flag Fen are in preparation to be sent to relevant bodies as above, as is a report on the excavation, coring and laboratory work at the Canada Farm site.

14.2.6 Output F

f. The verification of the geophysical case studies against trial excavations or prior knowledge to allow evaluation of the various techniques (objective 7)

Ground truthing investigations were able to be carried out on four out of eight sites examined. Unfortunately, neither of the sites in the Preseli Hills were included in this, but excavations should take place in the next few years at Carn Menyn as part of the SPACES project, so the geophysical surveys at Llach Y Flaiddast will eventually be tested. The work at Drizzlecombe was not directly ground-truthed, but took place after the excavations at Yellowmead, and the interpretations of the surveys there were substantially informed by the Yellowmead excavation and laboratory results. At the outset of the project, when these objectives were formed, the results from the Canada Farm site over the Sweet Track were not at all expected. The chemical investigations of the peat there became much more than a simple excavation to check the survey interpretation. The ground truthing work here has raised many more questions about the relationship between ground water / peat chemistry in these environments, and both how the variations came about, and exactly how they affected the survey results. A great deal more research needs to be done in this area.

Despite these unforeseen complications, the background research conducted into each of the sites, and the ground truthing work, where it could take place, allowed an assessment of the performance of the geophysical techniques on each particular site.

This evaluation is given in the relevant case study chapter, and also discussed above in Chapter 13.

14.2.7 Output G

  g. Explanations for the success or failure of the techniques in each case study (objective 10)

Though a complete understanding of the geophysical response in these environments will require more surveys, more ground truthing, and more research into peat chemistry and the affect it has on survey, generally speaking this output has been met. Each of the case study chapters examines and evaluates the survey results in this way. On some sites, particularly at Canada Farm, ground truthing work was needed to explain the anomalies seen in the results, and whilst the exact mechanisms are yet to be understood, I am confident in the assertion that the reason the trackway was picked up indirectly by so many techniques is differential distribution of elements and compounds that influence geophysical survey responses.

14.2.8 Output H

  h. The production of a set of guidelines for archaeological geophysical survey in peatland environments

This output was the overall aim of the research project, and is presented in section 14.6, below.

Sections 14.3 to 14.5 deal with the 'key questions' established from the aims and objectives in Chapter 1.

14.3. Can conventional geophysical techniques be of use in the investigation of archaeological research (or development, or conservation) queries in these landscapes?

The case study surveys and an examination of the literature shows that conventional techniques are challenging to apply in these environments, but are well worth pursuing. At each of the case study sites, the surveys have helped to resolve research questions that would otherwise be much harder to investigate. Even at Flag Fen, where the main objectives of delimiting the Bronze Age timbers could not be met, whole landscapes were demonstrated through the surveys that raise important questions about what happened on the site after the platform and post alignment were buried.

There are caveats about survey resolutions, technical aspects of survey and how we classify the environments (see below), but in general these conventional techniques are more useful than anticipated. In the uplands, the greatest successes were achieved with resistivity and radar surveys, with the utility of electromagnetic and magnetometer survey being dependant on the type of igneous geology involved, and the site history, as magnetic prospection is more responsive on settlement sites. In the lowland environments, the situation was much more complex, with the benefits of each particular technique being very dependant on highly local factors of soil development and moisture content. One thing that was very clear from the case study surveys was that survey with more than one technique is highly recommended, both for cross verification between surveys that respond to similar soil properties, or to cover as wide a range of possible anomaly types. This is particularly important in these environments, as the results of one technique are often ambiguous and need comparison with others to tease out the right interpretation.

GPR responded well in most of the environments where it was deployed. It is very useful for peatland environments because it inherently deals with responses over depth, as well as in two-dimensional space, and as shown in section 1, the main

difference between peatland survey and most 'dry land' sites is the move from two-dimensional information to three.

14.4 If they work, exactly what properties of the peat and the archaeology are being detected? If they fail, what is causing this and can it be reliably predicted?

This question turned out to be very complicated. For the upland case studies the geophysical response does seem to directly be being caused by archaeological features, and to changes in the soil development due to human activity impacting on pedogenesis. At Llach y Flaiddast, the igneous geology caused some problems for the magnetic techniques. In the lowlands, the situation is less clear. At the Canada Farm site, the archaeology was indirectly detected through its impact on the groundwater and chemistry, leading to mineral precipitation in the peat profile. Though it must be noted that the GPR response did seem to be directly a reflection from the timbers. It remains to be seen whether this situation was a unique combination of the archaeology and hydrology of this particular site, or if other wooden structures could be detected by these proxy means. Certainly the results of geophysical surveys at Fiskerton did not produce a similar response (Martin 2002; Linford, N 2003). At Flag Fen, the features that were detected were almost certainly observed directly, but none of the prehistoric timber was located. This 'failure' is almost certainly caused by a combination of surface desiccation (overwhelming more faint responses from below this layer) and the presence of interleaving alluvial sediments, further masking the Bronze Age features on the site.

In many respects, it should be possible to plan for these sorts of obstacles predicted in advance of survey, with investigations to determine the geology and pedology of the site ahead of surveys taking place. For some sites, it might be possible to mitigate for them; for example, using a lower frequency radar at Flag Fen to try to reduce the losses created by the clays in the soil profile, or by using a smaller twin probe array on upland sites where the peat soils are thin and highly conductive. For other sites, such pre-survey investigations might suggest other prospection methods might be more appropriate, such as a combination of augering and microtopographical survey (Chapman & Van de Noort 2001; Challands 2003). It should be possible, where

enough is known in advance about the sediments, to approach survey in peatland environments with some confidence. This leads us to a new question:

14.4.1 Is the current classification system adequate for both environment types and the expected archaeology?

In short, no. The upland/lowland distinction commonly employed is manifestly not adequate. It is far too simplistic, particularly in the lowlands where more research is needed to examine the hydrological and chemical properties of the peat, along with the type of expected archaeology and the landscape position (both at present and in the past) in order to evolve a new schema, or identify one from the ecological literature that matches our needs as archaeologists and geophysicists. At present it is not completely clear *how* the geochemistry and hydrology of these sites influence the geophysical responses, but it is certain that they do affect them. As discussed above, the answer may well be an effort towards coring or geoarchaeological studies in advance of or in conjunction with geophysical survey in these peatlands, at least until these important relationships are better understood. This brings us neatly to our next question:

14.5. What role should ground truthing play in these environments?

Decent ground truthing operations, either directly or by comparison with known comparable sites have been shown to be essential in these environments. Not enough comparisons are available at present, and a focus of future research needs to be on ground truthing surveys in these environments, with a specific emphasis on geochemistry and hydrology, as well as archaeological interpretation.

14.5.1 Did the surveys stand up to the limited ground truthing work we were able to carry out?

The ground truthing work largely confirmed our interpretations of the sites, but also exposed some important contradictions, such as the strong reflections obtained from the upcast 'natural' at Yellowmead Down. Flag Fen was shown to be much drier and much less peaty than had been assumed from both the literature about the excavations,

and the resistivity inversions modelled for Area 1. Ground truthing was particularly important at Canada Farm, and confirmed the interpretation of the electrical and magnetic anomalies associated with the Sweet Track as being caused indirectly by its influence on the hydrology of the immediate environment. In all cases, the ground truthing work showed information not available from the surveys alone, and assisted in resolving ambiguous interpretations, such as the cause of the parch mark and resistivity and radar anomalies at Flag Fen Area 1.

Ground-truthing is vital, and needs to be undertaken in these challenging environments as they will build up our body of knowledge and assist in interpretations for years to come. There are not at present enough comparable surveys, which have been ground- truthed, to allow inferences between different sites in similar landscapes, and this needs urgent remedy, if geophysical survey is going to play a part in locating and protecting these important sites.

14.6 The toolkit- suggestions for future practice

This section has been designed to stand alone as a set of guidelines to the practitioner.

<u>Prior to and during survey</u>:

i. Understanding the specific sediment sequence on each survey site is the key to getting results, and making a useful interpretation. Wherever possible examine the sediment sequence in the immediate area of the survey. Direct observations are best, ideally working in conjunction with an environmental or geoarchaeological specialist. Where this is not possible, make use of previous work on the landscape, or make inferences from similar sites, but be careful as the sediment sequence can change rapidly over very short distances. It is important to look for layers that might inhibit or otherwise affect your chosen survey methods. This applies equally in the uplands and the lowlands. In the uplands, also be aware of the solid geology and outcrops, to allow for magnetic thermoremnance.

ii. Follow general best practice guidelines (English Heritage 2008) carefully, but be prepared to adapt strategies away from familiar techniques as the situation demands; for example, over thin blanket bog, a 0.25m resistivity array may be more appropriate than 0.5m, though transect and measurement intervals would also need to be reduced accordingly.

iii. It is essential to get good topographical surveys alongside the geophysical ones, taking care to map not just the terrain but to note changes in vegetation cover, footpaths and other surface features, such as any upstanding archaeology. Vegetation changes at the surface can indicate different peat types or formation conditions underneath them. Archaeological features in these environments can be very ephemeral, and so surface features can show more strongly in the results than underlying archaeology.

<u>Different guidelines for upland and lowland peat surveys now follow</u>:

iv. In the **uplands**, resistivity survey and GPR have been shown to work well, though investigations are needed into alternative resistivity arrays.

Gradiometry is of limited use, except on sites where settlement or industrial activity is expected and the igneous geology is not strongly thermoremnantly magnetic. Despite problems with resolution, EM surveys have proved useful as a rapid but complementary technique, helpful in verifying other anomalies.

If at all possible, avoid using techniques in isolation. If it only possible to use one, GPR should be the favoured option, making careful use of topographic corrections as needed. Twin probe resistivity arrays were shown to be directionally sensitive under certain conditions, so where this technique is used, ensure array orientation is maintained with respect to the remote probes. Bear in mind as well, that over thinner peats, inverse responses may be produced in resistivity survey by the presence of a thin conductive layer overlying a resistive parent material.

v.   In **lowland** peat environments, it is hard to make concrete recommendations about the best techniques and survey approach. Ideally, techniques would only be selected after a thorough examination of the survey environment, as discussed in point i. A key focus however, needs to be on techniques that can resolve information over depth as well as in over a 2 dimensional area. Even in areas where there are problematic, dissipative layers, GPR can provide useful information about the landscape and any features overlying the alluvium. Lower frequency radar investigations are more useful if the archaeological targets are predicted to be large. Similarly, ERT or Geonics EM31 surveys might be useful to resolve questions about the sediment sequence, and potentially identify archaeological targets.

vi.   As with the uplands, the use of multiple techniques is strongly recommended, and while depth-based information should always be sought, techniques like gradiometry should not be ruled out automatically: gradiometer survey detected parts of a buried landscape at Flag Fen, and helped verify the GPR results. As more surveys are completed and ground-truthed, it should be possible to refine these suggestions further. Many of these principles will also apply to deeper peat deposits in the uplands.

In time, a new way of classifying these environments should be developed, but this will in part rely on further geophysical surveys. Guidelines could then be developed for each specific environment, but at the moment, the complexities are not well enough understood.

Post Survey:

vii.   Ground truthing of the archaeological interpretation of geophysical surveys in these environments is vital. This begins with inspection trenches or coring programs, but wherever possible should also include laboratory examination of the key characteristics shown to influence the geophysical response; moisture content, loss on ignition, particle size distribution and magnetic susceptibility. Where chemical changes are thought to be an issue, chemical analysis should also be considered. These should be planned into the survey agenda, and form part of the reporting of the surveys.

viii.   Where the surveyor is not doing the follow-up excavations, such as in development/ planning situations, the need for communication between the excavator and surveyor is high, to allow combined interpretations to be formed, and to allow the geophysicist to explore any problems with the interpretation. Local curators have a vital role to play in this process.

ix.   The results of the surveys, ground truthing and follow up work must be disseminated. Publication is the preferred route, but where this is not possible, report summaries (at least) should be lodged with English Heritage for inclusion in the survey database, and with the Archaeological Investigations Project so that other researchers can access and build on the conclusions. It is also useful for archaeogeophysicists to take these results to non-geophysical conferences, to engage with the wider discipline, and to gain feedback and insight from other specialisations such as geoarchaeology.

14.7 Areas for further research

This research project demonstrated the potential for multiple avenues of further investigation. Essentially, we have a basic 'toolkit' of techniques and understanding that can be applied to peatland environments. That toolkit now needs to be refined.

It would be useful to return to Flag Fen and adapt the techniques already employed to try to get a response from below the alluvium that would allow the mapping of the Bronze Age timbers. This would ideally entail using a low frequency (100MHz) radar antenna and using an ERT array rather than multiplexed twin probe surveys to get electrical pseudosections or 3D data-blocks from key areas of the site.

The techniques evaluated here have been surprisingly successful in the uplands. It would be worthwhile to press on this area and examine some different site types, and some deeper peat deposits. It would also be very useful to do some comparison work between different types of resistivity arrays and survey intervals to get a better resolution of the archaeological features. Upland peat has been somewhat neglected until recently (Brunning 2007, 43), and geophysical survey has the potential to be a powerful research tool in these landscapes.

The radar response to archaeological waterlogged wood also needs some further investigation. The results from the Sweet Track suggest that it does produce radar reflections, but more specific information is required. A collaboration with Prof. Nigel Cassidy at Keele University has begun, obtaining directly measured relative dielectric permittivity values for samples from the site, both peat and wood. Once the results are obtained, it should be possible to produced forward models of the peat and wood, and investigate the optimum conditions for detection within a software model. These could then be trialled in sandbox-type tests and at sites with known archaeology, and further verified with keyhole ground truthing investigations.

The chemical and hydrological questions raised by the Sweet Track survey are only partially resolved, and research effort needs to be made in this area, though this would be an ambitious project. Tied into this is the possibility of using geophysical survey as

a monitoring technique that would involve little or no intrusive work on these fragile sites.

This study has highlighted some issues for archaeological geophysics as a discipline too. Geophysicists need to be more actively engaged in ground truthing work on their own surveys, creating feedback loops that challenge and develop interpretations. As a discipline we need to be better at publishing our results, and wherever possible, the data that generated them. Even if publication is not possible, surveys should at least be reported to English Heritage and the AIP in summary, to assist future researchers and surveyors. We also need to talk to other specialities and engage with the wider discipline; in some ways archaeological geophysics is in a similar position to wetland archaeology, in danger of becoming isolated from theoretical developments and paradigm shifts in archaeology as a whole.

Bibliography

Armstrong, K, 2008. Archaeological Prospection in Peatland Environments: thinking in 3D Presented at: *Computer Applications in Archaeology UK Chapter Meeting. February 1-2, 2008,* University of York.

Armstrong, K, 2009, *Interim Reporting on Ground Truthing Excavations at Yellowmead Down, Sheepstor (Devon), October 2008*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park HER & English Heritage

Armstrong, K, 2009b. Archaeological excavations at Yellowmead Stone Circles, *Dartmoor Matters,* The Dartmoor Preservation Association, Spring 2009, 10-11.

Armstrong, K, 2009c. Yellowmead stone circles, Sheepstor, *Dartmoor Magazine.* 94, 35-6.

Armstrong, K & Cheetham, P, 2008a, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Survey at Flag Fen. Area One pilot project, September 2007, Radar and Resistance Tomography Supplemental Report*: Unpublished limited circulation report. Copy accessed at: Bournemouth University & Fenland Archaeological Trust

Armstrong, K & Cheetham, P, 2008b. Archaeological Geophysical Prospection in Peatland Environments: Locating the Sweet Track at Canada Farm, Shapwick Heath (Somerset) Presented at: *Recent Work in Archaeological Geophysics. December 2008,* The Geological Society, Burlington House, London.

Armstrong, K & Cheetham, P, 2008c, *Archaeological Geophysical Survey in Peatland Environments: Case Study Survey of the Sweet Track in the Somerset Levels. Surveys Near Canada Farm and The Old Peat Works, November to December 2007, Preliminary Report*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, English Heritage and Somerset HER

Armstrong, K & Cheetham, P, 2008d. Locating the Sweet Track: Trialling Archaeological Geophysical Prospection in Peatland Environments. Presented at: *EIGG Postgraduate Symposium. August 2008,* British Geological Survey, Keyworth, Nottingham.

Armstrong, K & Cheetham, P, 2008e. *Archaeological Geophysical Prospection in Peatland environments: Case study survey at Flag Fen Area One pilot project,*

September 2007. Unpublished limited circulation report. Copy accessed at Bournemouth University and Fenland Archaeological Trust

Armstrong, K & Cheetham, P, 2009a, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Surveys at Drizzlecombe Stone Row Complex, Dartmoor, Devon*

Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park HER, English Heritage

Armstrong, K & Cheetham, P, 2009b, *Archaeological Geophysical Prospection in Peatland Environments: Case Study Surveys at Yellowmead Multiple Stone Circles and an adjacent Cairn, Yellowmead Down, Sheepstor, Dartmoor*: Unpublished limited circulation report. Copy accessed at: Bournemouth University, Dartmoor National Park Authority HER, English Heritage

Armstrong, K & Cheetham, P, 2009c, *Archaeological Geophysical Survey in Peatland Environments: Case Study Survey at Flag Fen, (Area 2), Peterborough, Cambridgeshire*: Unpublished limited circulation report. Copy accessed at: Bournemouth University & Fenland Archaeological Trust

Armstrong, K, Darvill, T & Cheetham, P, 2009. Archaeological geophysical prospection in peatland environments: case studies and suggestions for future practice Presented at: *Memoire du sol, espace des hommes; the 8th International conference on Archaeological Prospection. September 9-12, 2009,* Arts et Metiers, Paris.

Arnott, S, Dix, J, Best, A & Gregory, D, 2005. Imaging of buried archaeological material: The reflection properties of archaeological wood. *Marine Geophysical Researches,* 26, 135-44.

Atkinson, R, 1946. *Field Archaeology*. London: Meuthen & Company.

Aston, M, Martin, M & Jackson, A, 1998. The potential for heavy metal soil analysis on low status archaeological sites at Shapwick, Somerset. *Antiquity,* 72, 838-47.

Avery, B & Bascomb, C (eds). 1982. *Soil Survey Laboratory Methods*. Harpenden: Soil Survey of England and Wales.

Bates, M, Bates, R & Whittaker, J, 2007. Mixed method approaches to the investigation and mapping of buried Quaternary deposits: Examples from southern England. *Archaeological Prospection,* 14, 104-29.

Benech, C, 2007. New approach to the study of city planning and domestic dwellings in the ancient Near East. *Archaeological Prospection,* 14, 87-103.

Berquist, A & Taylor, T, 1987. The origin of the Gundestrup cauldron. *Antiquity,* 61, 10-24.

Bevan, B, 2000a. An early geophysical survey at Williamsburg, USA. *Archaeological Prospection,* 7, 55-8.

Bevan, B, (nd) *The pole-pole resistivity array compared to the twin electrode array,* Available on-line at: http://www.cast.uark.edu/nadag/EducationalMaterials/Bevan/Bevan1.pdf [Accessed: 15/05/2007].

Bindler, R, 2006. Mired in the past- looking to the future: Geochemistry of peat and the analysis of past environmental changes. *Global and Planetary Change,* 53, 209-21.

Booth, A, Linford, N, Clark, R & Murray, T, 2008. Three-dimensional, Multi-offset ground penetrating radar imaging of archaeological targets. *Archaeological Prospection,* 15, 93-112.

Boreham, S, Boreham, J & Rolfe, C, 2009. Unlocking the preservation potential of archaeological sediments: Three case studies from English wetlands. Presented at: *Geoarchaeology 2009. April 15th- 17th 2009,* Sheffield University.

Bournemouth University, *The Archaeological Investigations Project*, Available on-line at: http://csweb.bournemouth.ac.uk/aip/aipintro.htm [Accessed: 17/01/2010].

Bradley, R, 1990. *The passage of arms. An archaeological analysis of prehistoric hoards and votive deposits.* Cambridge: Cambridge University Press.

Bradley, R, 1998. *The significance of monuments: on the shaping of human experience in Neolithic and Bronze Age Europe.* London: Routledge.

Bradley, R, 2000. *An archaeology of natural places.* London: Routledge.

Bradley, R, 2003. A life less ordinary: The ritualization of the domestic sphere in later prehistoric Europe. *Cambridge Archaeological Journal,* 13, 5-23.

Brailsford, J W, 1938. Bronze Age stone monuments of Dartmoor. *Antiquity,* 12, 444-63.

Bruck, J, 1999. Ritual and rationality: Some problems of interpretation in European archaeology. *European Journal of Archaeology,* 2, 313-44.

Brunning, R, 2007. Monitoring waterlogged sites in peatlands: where, how, why and what next? *In:* Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Proceedings of the 11th international wetland archaeology research project conference, Edinburgh, 2005.* Edinburgh: Society of Antiquaries of Scotland.

Burl, A, 1993. *From Carnac to Callanish: the prehistoric stone rows and avenues of Britain, Ireland and Brittany.* London: Yale University Press.

Burton, R G O & Hodgson, J M, 1987. *Lowland peat in England and Wales.* Harpenden: Lawes Agricultural Trust (Soil Survey of England and Wales).

Butler, J, 1994. *Dartmoor atlas of antiquities: Volume three- the south-west.* Exeter: Devon Books.

Caple, C, 1994. Reburial of waterlogged wood, the problems and potential of this conservation technique. *International Biodeterioration and Biodegradation,* 34, 61-72.

Carey, C, Brown, T, Challis, K, Howard, A & Cooper, L, 2006. Predictive modelling of multiperod geoarchaeological resources at a river confluence: A case study from the Trent-Soar, UK. *Archaeological Prospection,* 13, 241-50.

Carr, C, 1982. *Handbook on soil resistivity surveying.* Evanston: Centre for American Archaeology Press.

Challands, A, 2003. Geophysical survey below peat? A simple magnetic susceptibility method. *In:* Jones, R, (ed). *Going over old ground: perspectives on archaeological geophysical and geochemical survey in Scotland; proceedings of a conference held at the Department of Archaeology, University of Glasgow, Scotland, August 2003.* Oxford: Archaeopress.

Challis, K & Howard, A, 2006. A review of trends within archaeological remote sensing in alluvial environments. *Archaeological Prospection,* 13, 231-40.

Challis, K, Kincey, M & Howard, A, 2009. Airborne remote sensing of valley floor geoarchaeology using Deadalus ATM and CASI. *Archaeological Prospection,* 16, 17-33.

Chapman, H & Van de Noort, R, 2001. High resolution wetland prospection using GPS and GIS: Landscape studies at Sutton Common (South Yorkshire) and Meare Village East (Somerset). *Journal of Archaeological Science,* 28, 365-75.

Cheetham, P, 2001. A symmetrical response, high resolution and reduced near-surface noise multiple potential electrode earth resistivity array for archaeological area

survey. *In*: Doneus, M, Eder-Hinterleitner, A & Neubauer, W, *Archaeological Prospection: Fourth international conference on archaeological prospection.*

Cheetham, P, 2005. Forensic geophysical survey. *In:* Hunter, J & Cox, M, (eds). *Forensic Archaeology: Advances in theory and practice.* London: Routledge.

Cheetham, P, 2008. Non-invasive sub-surface mapping techniques, satellite and aerial imagery in landscape archaeology. *In:* Thomas, J & Bruno, D, (eds). *Handbook of landscape archaeology.* Walnut Creek: Left Coast Press.

Clark, A, 1996. *Seeing beneath the soil: prospecting methods in archaeology (revised edition).* London: Routledge.

Clark, J, 1971. *Excavations at Star Carr: An early Mesolithic site at Seamer, near Scarborough, North Yorkshire* (Second, revised edition). Cambridge: Cambridge University Press.

Clarke, C, Utsi, E & Utsi, V, 1999. Ground penetrating radar investigations at North Ballachulish Moss, Highland, Scotland. *Archaeological Prospection,* 6, 107-21.

Clymo, R, 1983. Peat. *In:* Gore, A, (ed). *Mires: Swamp, bog, fen and moor. General studies. Ecosystems of the World 4A.* Oxford: Elsevier. 159-224.

Cunliffe, B, 1986. The Iron Age. *In:* Darvill, T, 1986. *The Archaeology of the Uplands: A rapid assessment of Archaeological Knowledge and Practice.* London : Royal Commission on the Historical Monuments of England

Coles, B (ed). 1990. *Organic archaeological remains in Southwest Britain: A survey of the available evidence. WARP Occasional Paper 4*. Exeter: Wetland Archaeological Research Project.

Coles, B (ed). 1991. *The wetland revolution in prehistory: proceedings of a conference held by The Prehistoric Society and WARP at the University of Exeter, April 1991*. Exeter: Wetland Archaeological Research Project.

Coles, B & Coles, J, 1986. *Sweet Track to Glastonbury: the Somerset Levels in prehistory.* London: Thames and Hudson.

Coles, B & Coles, J, 1989. *People of the wetlands: Bogs, bodies and lake dwellers.* London: Thames and Hudson.

Coles, J, 1987. The case for wet archaeology. *In:* Coles, J & Lawson, A, (eds). *European Wetlands in Prehistory.* Oxford: Clarendon Press.

Coles, J, 1996. *Enlarging the past: the contributions of wetland archaeology. The Rhind lectures 1994-5.* Exeter: Wetland Archaeological Research Project.

Coles, J & Lawson, A (eds). 1987. *European Wetlands in Prehistory*. Oxford: Clarendon Press.

Coles, J & Orme, B, 1976b. The Sweet Track, Railway Site. *The Somerset Levels Papers,* 2.

Comas, X, Slater, L & Reeve, A, 2004. Geophysical evidence for peat basin morphology and stratigraphic controls on vegetation observed in a northern Peatland. *Journal of Hydrology,* 295, 173-84.

Conneller, C, 2004. Becoming deer. Corporeal transformations at Star Carr. *Archaeological Dialogues,* 11, 37-56.

Conyers, L B, 2004. *Ground Penetrating Radar for Archaeology.* Walnut Creek: AltaMira.

Conyers, L B, 2006. Ground penetrating radar. *In:* Johnson, J, (ed). *Remote sensing in archaeology: An explicitly North American perspective.* Tuscaloosa: University of Alabama Press. 131-59.

Conyers, L B, Ernenwein, E, Grealy, M & Lowe, K, 2008. Electromagnetic conductivity mapping for site prediction on meandering floodplains. *Archaeological Prospection,* 15, 81-91.

Cox, C, 1992. Satellite imagery, aerial photography and wetland archaeology: An interim report on an application of remote sensing to wetland archaeology: The pilot study in Cumbria, England. *World Archaeology,* 24, 249-67.

Craddock, P, Gurney, D, Pryor, F & Hughes, M, 1985. The application of phosphate analysis to the location and interpretation of archaeological sites. *Archaeology Journal,* 142, 361-76.

Crowther, J, 2003. Potential magnetic susceptibility and fractional conversion studies of archaeological soils and sediments. *Archaeometry,* 45, 685-701.

Dalan, R A, 2006. A geophysical approach to buried site detection using down-hole susceptibility and soil magnetic techniques. *Archaeological Prospection,* 13, 182-206.

Dalan, R A & Banerjee, S K, 1998. Solving archaeological problems using techniques of soil magnetism. *Geoarchaeology,* 13, 3-36.

Dartmoor Preservation Association, 2008. *Hill Farming*, Available on-line at: http://www.dartmoorpreservation.com/campaign_hillfarming.htm# [Accessed: 01/11/2009].

Darvill, T, 1986. *The Archaeology of the Uplands: A rapid assessment of Archaeological Knowledge and Practice.* London : Royal Commission on the Historical Monuments of England

Darvill, T, 1987. *Ancient monuments in the countryside: an archaeological management review.* London : Royal Commission on the Historical Monuments of England

Darvill, T, 2002. *The concise Oxford dictionary of archaeology.* Oxford: Oxford University Press.

Darvill, T, Wainwright, G, Armstrong, K, & Ixer, R, 2009, Strumble-Preseli ancient communities and environment study (SPACES): Sixth report 2007–08. *Archaeology in Wales,* 48, 47–56.

Darvill, T, Evans, D, Fyfe, R & Wainwright, G, 2005. Strumble-Preseli Ancient Communities and Environment Study (SPACES): Fourth Report 2005. *Archaeology in Wales,* 45, 17-23.

Darvill, T, Evans, D & Wainwright, G, 2003. Strumble-Preseli Ancient Communities and Environment Study (SPACES): Second Report 2003. *Archaeology in Wales,* 43, 3-12.

Darvill, T, Evans, D & Wainwright, G, 2004. Strumble-Preseli Ancient Communities and Environment Study (SPACES): Third Report 2004. *Archaeology in Wales,* 44, 104-9.

Darvill, T & Russell, B, 2002. *Archaeology after PPG16: archaeological investigations in England 1990-1999 (Bournemouth University School of Conservation Sciences Research Report 10.* Bournemouth and London: Bournemouth University in association with English Heritage.

Darvill, T & Wainwright, G, 2002. SPACES- exploring Neolithic landscapes in the Strumble-Preseli area of southwest Wales. *Antiquity,* 76, 623-624.

David, A, *Geophysical Survey in archaeological field evaluation*, Available on-line at: http://www.english-heritage.org.uk/upload/pdf/Geophysical_Survey_in_Archaeological_Field_Evaluation_1995.pdf [Accessed: 30/05/2007].

Dean, R, 2003, *A gradiometer survey at Langstone Moor Stone Circle, Peter Tavy, Devon, NGR SX55637819*: Unpublished limited circulation report. Copy accessed at: Dartmoor National Park Authority

Dearing, J, 1999. *Environmental magnetic susceptibility: Using the Bartington MS2 system (revised edition).* Kenilworth: Chi Publishing.

DEFRA, 2006. Ramsar sites in England- A policy statement [online], available from: http://www.defra.gov.uk/rural/documents/protected/ramsar-policy.pdf [accessed 27/01/10]

Devon County Council, 1992, *Devon Historic Environment Record: 3338* Exeter: Devon County Council Archaeology Service [unpublished database record accessed 11/07/2007]

Dewar, I, Batt, C & Peters, C, 2002. A mineral magnetic investigation into fuel derived deposits from Old Scatness Broch, Shetland. *Physics and Chemistry of the Earth,* 27, 1343-8.

Dincauze, D, 2000. *Environmental archaeology: principles and practice.* Cambridge: Cambridge University Press.

Donnelly, L, 2008, Discussions at Geological Society forensic geosciences meeting, Burlington House, London, 17/12/08 (personal communication).

Egloff, M, 1987. 130 years of archaeological research in Lake Neuchatel, Switzerland. *In:* Coles, J & Lawson, A, (eds). *European wetlands in prehistory.* Oxford: Clarendon Press.

English Heritage, *Fylingdales Moor*, Available on-line at: http://www.english-heritage.org.uk/server/show/nav.9425 [Accessed: 27/01/2010].

English Heritage, 2008. *Geophysical Survey in Archaeological Field Evaluation* (2nd Edition). Swindon: English Heritage.

Ernenwein, E & Kvamme, K, 2008. Data processing issues in large-area GPR surveys: correcting trace misalignments, edge discontinuities and striping. *Archaeological Prospection,* 15, 133-49.

ESRI, 2005. *Arc Map 9.1.* (computer programme). Redlands, CA: ESRI incorporated.

Essington, M, 2003. *Soil and Water Chemistry: an integrative approach.* Boca Raton: CRC Press.

Field, N & Parker Pearson, M, 2002. *Fiskerton: an Iron Age timber causeway with Iron Age and Roman votive offerings.* Oxford: Oxbow.

Finn, C, 1999. Words from kept bodies- The bog body as literary inspiration. *In:*. Coles, B, Coles, J & Jorgensen, M (eds) *Bog Bodies, Sacred Sites and Wetland Archaeology. Proceedings of a conference held by WARP and the National*

Museum of Denmark in conjunction with Silkeborg Museum, Jutland, September 1996. Exeter, WARP

Fleming, A, 1988. *The Dartmoor Reaves: investigating prehistoric land divisions.* London: Batsford.

French, & Pryor, F, 1993. *The South-West Fen Dyke survey project 1982-86.* Peterborough: Fenland Archaeological Trust.

French, C, 2003a. The Fengate shore, lower Nene valley and the Flag Fen basin, Cambridgeshire, England. *In:* French, C, (ed). *Geoarchaeology in action: studies in soil morphology and landscape evolution.* London: Routledge.

French, C, 2003b. *Geoarchaeology in action: studies of soil micromorphology and landscape evolution.* London: Routledge.

French, C, 2010, Discussions during Viva Voce examination, Bournemouth University, 20th May 2010 (personal communication).

Frenzel, B, 1983. Mires- Repositories of climatic information or self-perpetuating ecosystems? *In:* Gore, A, (ed). *Mires: Swamp, bog, fen and moor. General studies. Ecosystems of the World 4A.* Oxford: Elsevier. 35-65.

G S B Prospection, 1999, *Flag Fen: Geophysical survey*: Unpublished limited circulation report. Copy accessed at: Fenland Archaeological Trust

Gaffney, C & Gater, J, 1993. Development of remote sensing, part 2 - Practice and method in the application of geophysical techniques in archaeology. *In:* Hunter, J & Ralston, I, (eds). *Archaeological resource management in the UK: An introduction.* Stroud: Sutton.

Gaffney, C & Gater, J, 2003. *Revealing the buried past: geophysics for archaeologists.* Stroud: Tempus.

Gater, J, 1981, *Hadrian's Wall resistivity survey*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology

Geoscan Research, 2006. *GEOPLOT* (computer program). Bradford: Geoscan Research

Godwin, H, 1978. *Fenland: Its ancient past and uncertain future.* Cambridge, Cambridge University Press

Goodman, D, 2008. *GPR-SLICE 6.0* (computer program). Woodland Hills, CA: Geophysical Archaeometry Laboratory

Goodman, D, 2008b. *GPR-SLICE Users Manual.* Woodland Hills, CA: Geophysical Archaeometry Laboratory

Haddon-Reece, D, 1977a, *Interim report on geophysics at Seamer Carr, database record # 472*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology Geophysical Survey Database, available at http://sdb2.eng-h.gov.uk/

Haddon-Reece, D, 1977b, *Report on further magnetometer survey at Seamer Carr, database record # 475*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology Geophysical Survey Database, available at http://sdb2.eng-h.gov.uk/

Haddon-Reece, D, 1977c, *Second interim report on magnetometer survey at Seamer Carr, database record # 473*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology Geophysical Survey Database, available at http://sdb2.eng-h.gov.uk/

Haddon-Reece, D, 1977d, *Third interim report on magnetometer and auger survey at Seamer Carr, database record # 474*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology Geophysical Survey Database, available at http://sdb2.eng-h.gov.uk/

Harding, A, 2000. *European societies in the Bronze Age*. Cambridge, Cambridge University Press.

Hargrave, M, 2006. Ground truthing the results of geophysical surveys. *In:* Johnson, J, (ed). *Remote sensing in archaeology: an explicitly North American perspective.* Tuscaloosa: University of Alabama Press.

Haslam, S, 2003. *Understanding wetlands: Fen bog and marsh.* London: Taylor and Francis.

Hayen, H, 1987. Peatbog archaeology in Lower Saxony, West Germany. *In:* Coles, J & Lawson, A, (eds). *European wetlands in prehistory.* Oxford: Clarendon Press.

Heany, S 1999. Plenary (Introduction) *In:.* Coles, B, Coles, J & Jorgensen, M (eds) *Bog Bodies, Sacred Sites and Wetland Archaeology. Proceedings of a conference held by WARP and the National Museum of Denmark in conjunction with Silkeborg Museum, Jutland, September 1996*. Exeter, WARP.

Heritage Management for England's Wetlands, 2002, *Hydrological Report for Flag Fen*: Unpublished limited circulation report. Copy accessed at: Fenland Archaeological Trust

Hesse, A, 2000. Count Robert du Mesnil du Buisson (1895–1986), a French precursor in geophysical survey for archaeology. *Archaeological Prospection,* 7, 43-9.

Hobbs, N, 1986. Mire morphology and the properties and behaviour of some British and foreign peats. *Quarterly Journal of Engineering Geology,* 19, 7-80.

Hodgson, J, Brennand, M & contributors, 2005. *North West Regional Archaeological Research Framework Prehistoric Period Research Agenda Draft February 2005*, Available on-line at: http://www.liverpoolmuseums.org.uk/mol/archaeology/arf/ [Accessed: 15/05/07].

Hodgson, J, Donohue, S, O'Connell, Y, Krahn, H, Reid, G & Young, M, 2009. A geophysical journey around Ireland *First Break,* 27, 35-42.

Howard-Davis, C, Stocks, C & Innes, J, 1998. *Peat and the past: a survey and assessment of the prehistory of the lowland wetlands of North-west England.* Lancaster: Lancaster University.

Johnson, J, 2006a. Introduction. *In:* Johnson, J, (ed). *Remote Sensing in Archaeology: An explicitly North American Perspective.* Tuscaloosa: University of Alabama Press.

Johnson, J (ed). 2006b. *Remote sensing in archaeology: An explicitly North American perspective*. Tuscaloosa: University of Alabama Press.

Johnson, J & Haley, B, 2006. A cost-benefit analysis of remote sensing application in cultural resource management archaeology. *In:* Johnson, J, (ed). *Remote sensing in archaeology: an explicitly North American perspective.* Tuscaloosa: University of Alabama Press.

Johnston, R, 2005. Pattern without a plan: Rethinking the Bronze Age coaxial field systems on Dartmoor, South-West England. *Oxford Journal of Archaeology,* 24, 1-21.

Johnston, R & Wickstead, H, 2005, *Geophysical surveys on Shovel Down and Kes Tor, Dartmoor, Devon 2003 and 2004*: Unpublished limited circulation report. Copy accessed at: University of Sheffield

Johnston, R, 2008. Later prehistoric landscapes and inhabitation. *In:* Pollard, J (ed) *Prehistoric Britain*. Oxford: Blackwell.

Joint Nature Conservation Committee, 2009. *Ramsar sites in the UK, its Oversees Territories and Crown Dependencies*, Available on-line at: http://www.jncc.gov.uk/page-161 [Accessed: 01/11/09].

Jol, H & Smith, D, 1995. Ground penetrating radar surveys of peatlands for oilfield pipelines in Canada. *Applied Geophysics,* 34, 109-23.

Jordan, D, 2009. How effective is geophysical survey? A regional review. *Archaeological Prospection,* 16, 77-90.

Kattenberg, A, 2008. *The application of magnetic methods for Dutch archaeological resource management (published PhD Thesis).* Amsterdam: vrije Universiteit.

Kattenberg, A & Aalbersberg, G, 2004. Archaeological prospection of the Dutch peri-marine landscape by means of magnetic methods. *Archaeological Prospection,* 11, 227-35.

Kearey, P, Brooks, M & Hill, I, 2002. *An introduction to geophysical exploration.* 3rd edition. Oxford: Blackwell Publishing.

Koster, E & Favier, T, 2005. Peatlands, past and present. *In:* Koster, E, (ed). *The physical geography of Western Europe.* Oxford: Oxford University Press. 161-81.

Klein, J & Lajoie, J, 1980. Electromagnetic prospecting for minerals. *In*: Blaricom, R, (ed). *Practical geophysics from the exploration geologist.* Spokane, Northwest Mining Association.

Kvamme, K, 2003. Geophysical surveys as landscape archaeology. *American Antiquity,* 68, 435-57.

Kvamme, K, 2006. Integrating multidimensional geophysical data. *Archaeological Prospection,* 13, 57-72.

Leckebusch, J, 2000. Two- and three-dimensional ground penetrating radar surveys across a Medieval choir: A case study in archaeology. *Archaeological Prospection,* 7, 189-200.

Leckebusch, J, 2001. Investigating the true resolution and three-dimensional capabilities of ground penetrating radar data in archaeological surveys: Measurements in a sand box. *Archaeological Prospection,* 8, 29-40.

Leckebusch, J, 2003. Ground penetrating radar: A modern three-dimensional prospection method. *Archaeological Prospection,* 10, 213-40.

Leckebusch, J, 2007. Pull-up/pull-down corrections for ground-penetrating radar data. *Archaeological Prospection,* 14, 142-5.

Leopold, M & Volkel, J, 2003. GPR Images of periglacial slope deposits in the central European Highlands, Germany. *In:* Bristow, C & Jol, H, (eds). *Ground*

penetrating radar in sediments. London: Geological Society, Special
Publications, 211. 181-9.

Lesch, S, Corwin, D & Robinson, D, 2004. Apparent soil electrical conductivity
mapping as an agricultural management tool in arid zones. *Computers and
Electronics in Agriculture,* 46, 351-78.

Lillie, M & Cheetham, J, 2002, *Water table monitoring at Flag Fen, Peterborough.*
Hull, Unpublished limited circulation report accessed at: Wetland
Archaeology & Environments Research Centre, University of Hull.

Lindsay, R, 1995. *Bogs: The ecology, classification and conservation of ombrotrophic
mires.* Perth: Scottish Natural Heritage.

Linford, N, 2003, *Report on ground penetrating radar survey at Fiskerton, Witham
Valley, Lincolnshire*: Unpublished limited circulation report. Copy accessed
at: English Heritage Centre for Archaeology

Linford, N, Lindford, P, Martin, L & Payne, A, 2007. Geophysical evidence for
assessing plough damage. Presented at: *Archaeological Prospection 7 / 2007.
11-15 September 2007,* Nitra, Slovakia.

Linford, P, *The English Heritage Geophysical Survey Database*, Available on-line at:
http://sdb2.eng-h.gov.uk/ [Accessed: 17/01/2010].

Lock, G, 2003. *Using computers in archaeology: towards virtual pasts.* London:
Routledge.

Loke, M H, *Electrical imaging surveys for environmental and engineering studies. A
practical guide to 2D and 3D surveys.*, Available on-line at:
http://www.terrajp.co.jp/lokenote.pdf [Accessed: 31/01/08].

Loke, M H, 2005. *Res2dinv 3.54* (computer program). Malaysia: Geotomo Software

Lynch, F, 1986, The Bronze Age. *In:* Darvill, T, 1986. *The Archaeology of the
Uplands: A rapid assessment of Archaeological Knowledge and Practice.*
London : Royal Commission on the Historical Monuments of England

Marmet, E, Bina, M, Fedoroff, N & Tabbagh, A, 1999. Relationships between human
activity and the magnetic properties of soils: a case study in the medieval site
of Roissy-en-France. *Archaeological Prospection,* 6, 161-70.

Martin, L, 2002, *Fiskerton, Witham Valley, Lincolnshire. Report on Geophysical
Surveys, August 2002. Iron Age causeway test surveys*: Unpublished limited
circulation report. Copy accessed at: English Heritage Centre for Archaeology

Mauriello, P, Monna, D & Patella, D, 1998. 3D geoelectric tomography and archaeological applications. *Geophysical Prospecting,* 46, 543-570.

Milsom, J, 1996. *Field geophysics (*2nd revised edition). London: Wiley

Montanarella, L, Jones, R & Hiederer, R, 2006. The distribution of peatland in Europe. *Mires and Peat,* 1, 1-10

National Monuments Record, 1993a, *National Monument Number 10749.* Swindon, National Monuments Record. [unpublished database record accessed 11/07/2007]

National Monuments Record, 1993b, *National Monument Number 10748.* Swindon, National Monuments Record. [unpublished database record accessed 11/07/2007]

National Monuments Record, 2000, *National Monument Number 24104: Inspectors Report.* Swindon, National Monuments Record. [unpublished database record accessed 11/07/2007]

Natural England, 2009. *Nature on the Map*, Available online at: http://www.natureonthemap.org.uk/map.aspx [Accessed 01/11/2009].

Natural England, 2009b. *Designated Areas*. Available online at: http://www.naturalengland.org.uk/ourwork/conservation/designatedareas/defa ult.aspx [accessed on 27/01/2009]

Nye, A, Harrison, W & Savory, H, 1983. Excavations at the Croesmihangel barrow, Pembrokeshire, 1958-9. *Archaeologia Cambrensis,* 132, 19-29.

O'Sullivan, A & Van de Noort, R, 2007. Temporality, cultural biography and seasonality: rethinking time in wetland archaeology. *In:* The Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Proceedings of the 11th international wetland archaeology research project conference, Edinburgh, 2005.* Edinburgh: Society of Antiquaries of Scotland.

Olivier, A & Van de Noort, R, 2002, *English Heritage strategy for wetlands.* London/Exeter, English Heritage/University of Exeter.

Paxman, J & Turner, C, 2008. Uplands campaign goes to Westminster. *Dartmoor Matters,* 168, 3-5.

Payne, A, 2003, *Report on geophysical surveys at Sutton Common Enclosures, South Yorkshire, database record # 2744*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology

Perini, R, 1987. The typology of the structures on Bronze Age wetland settlements at Fiave and Lavagnone in the Italian Alpine foothills. *In:* Coles, J & Lawson, A, (eds). *European wetlands in prehistory.* Oxford: Clarendon Press.

Peters, C, Thompson, R, Harrison, A & Church, M, 2002. Low temperature magnetic characterisation of fire ash residues. *Physics and Chemistry of the Earth,* 27, 1355-61.

Petit, P, 1974. *Prehistoric Dartmoor.* Dawlish: W J Holman Limited.

Piro, S, Mauriello, P & Cammarno, F, 2000. Quantitative integration of geophysical methods for archaeological prospection. *Archaeological Prospection,* 7, 203-13.

Plets, R, Dix, J & Best, A, 2007. Characterization of buried inundated peat in seismic (chirp) data, inferred from core information. *Archaeological Prospection,* 14, 261-72.

Pryor, F, 1992a. Current research at Flag Fen, Peterborough. *Antiquity,* 66, 439-57.

Pryor, F, 1992b. Discussion: the Fengate/Northey landscape. *Antiquity,* 66, 518-31.

Pryor, F, 2001. *The Flag Fen basin. Archaeology and environment of a fenland landscape.* Swindon: English Heritage.

Pryor, F, 2005. *Flag Fen: Life and death of a prehistoric landscape.* Stroud: Tempus.

Quartermaine, J, Cook, J, Druce, D & Huckerby, E, 2007. The trials and tribulations of upland peat: results of investigations into the archaeological potential of the higher peatlands. *In:* Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Proceedings of the 11th international wetland archaeology research project conference, Edinburgh, 2005.* Edinburgh: Society of Antiquaries of Scotland.

Quinn, R, Bull, J & Dix, J, 1997. Imaging wooden artefacts using Chirp sources. *Archaeological Prospection,* 4, 25-35.

Raftery, B, 1986. A wooden trackway of Iron Age date in Ireland. *Antiquity*, 60, 50-4.

Rendell, P, 2009. Are we loosing Dartmoor's history? *Dartmoor Magazine*, 94, 52-3.

Richards, J, 1997. Preservation and re-use of digital data: the role of the Archaeology Data Service. *Antiquity,* 71, 1057.

Richards, J, 2002. Digital preservation and access. *European Journal of Archaeology,* 5, 343-66.

Ruffell, A, 2002. Remote detection and identification of organic remains: An assessment of archaeological potential. *Archaeological Prospection,* 9, 115-22.

Scaife, R, 2001. Flag Fen- The vegetation and environment. *In:* Pryor, F. *The Flag Fen basin. Archaeology and environment of a fenland landscape.* Swindon: English Heritage.

Schleifer, N, Weller, A, Schneider, S & Junge, A, 2002. Investigation of a Bronze Age plankway by spectral induced polarization. *Archaeological Prospection,* 9, 243-53.

Scollar, I, Tabbagh, A, Hesse, A & Herzog, I, 1990. *Archaeological prospecting and remote sensing (Topics in remote sensing 2).* Cambridge: Cambridge University Press.

Sikora, L & Keeney, D, 1983. Further aspects of soil chemistry under anaerobic conditions. *In:* Gore, A, (ed). *Mires: Swamp, bog, fen and moor. General studies. Ecosystems of the World 4A.* Oxford: Elsevier.

Simmons, I G, 1996. *The environmental impact of later Mesolithic cultures: The creation of moorland landscape in England and Wales.* Edinburgh: Edinburgh University Press.

Simmons, I G, 2003. *The moorlands of England and Wales, an environmental history 8000 BC to AD 2000.* Edinburgh: Edinburgh University Press.

Slater, L & Reeve, A, 2002. Case history: Investigating peatland stratigraphy and hydrogeology using integrated electrical geophysics. *Geophysics,* 67, 365-78.

SPSS Incorporated, 2006. *SPSS v.15 for windows* (computer program). Chicago: SPSS Incorporated

Tabbagh, A, 1986. Applications and advantages of the slingram electromagnetic method for archaeological prospecting. *Geophysics,* 51, 576-84.

Taylor, M & Pryor, F, 1990. Bronze Age building techniques at Flag Fen, Peterborough, England. *World Archaeology,* 21, 425-34.

Theimer, B, Nobes, D & Warner, B, 1994. A study of the geoelectrical properties of peatlands and their influence on ground-penetrating radar surveying. *Geophysical Prospecting,* 42, 179-209.

Thier, K, 2007. Talking about wetlands in the past. *In:* Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Proceedings of the 11th international wetland archaeology research project conference, Edinburgh, 2005.* Edinburgh: Society of Antiquaries of Scotland.

Thompson, R & Oldfield, F, 1986. *Environmental magnetism.* London: Allen & Unwin.

Tolkien, J, 1954. *The return of the king.* London: George Allen & Unwin.

Utsi, E, 2003. Sinking into old ground: Ground probing radar in the Scottish wetlands. *In*: Jones, R, *Going over old ground: perspectives on archaeological geophysical and geochemical survey in Scotland; proceedings of a conference held at the Department of Archaeology, University of Glasgow, Scotland, August 2003.* Oxford: Archaeopress

Utsi, E, 2004. Ground penetrating radar timeslices from North Ballachulish Moss. *Archaeological Prospection,* 11, 65-75.

Utsi, E, 2007. Wetlands viewed through the antennas of a ground penetrating radar. *In:* Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Procedings of the 11th WARP conference, Edinburgh 2005.* Edinburgh: Society of Antiquaries of Scotland.

Utsi Electronics, 2001, *Trial GPR surveys of three sites in the Somerset Levels: Part 1- A section of the Sweet Track 2nd July 2001*: Unpublished limited circulation report. Copy accessed at: English Heritage Centre for Archaeology

Van Dam, R, Schlager, W, Dekkers, M & Huisman, J, 2002. Iron oxides as a cause of GPR reflections. *Geophysics,* 67, 536-45.

Van de Noort, R, 2002a. Bronze Age perception of wetlands: recent archaeological work in the Humber estuary. *In:* Raftery, B & Hickey, J, (eds). 2002 *Recent developments in wetland research.* Dublin: Seandalaiocht.

Van de Noort, R, 2002b. Flat, flatter, flattest- the English Heritage wetland surveys in retrospect. *In:* Lane, T & Coles, J, (eds). *Through wet and dry: essays in honour of David Hall.* Lincolnshire Archaeology and Heritage reports series; No. 5.

Van de Noort, R, Fletcher, W, Thomas, G, Carstairs, I & Patrick, D, 2002, *Monuments at risk in England's wetlands*. London/ Exeter, English Heritage/ University of Exeter.

Van de Noort, R & O'Sullivan, A, 2006. *Rethinking wetland archaeology.* London: Duckworth.

Van de Noort, R & O'Sullivan, A, 2007. Places, perceptions, boundaries and tasks: rethinking landscapes in wetland archaeology. *In:* Scottish Wetland Archaeology Project, (ed). *Archaeology from the wetlands: recent perspectives. Proceedings of the 11th international wetland archaeology*

research project conference, Edinburgh, 2005. Edinburgh: Society of Antiquaries of Scotland.

Volkel, J, Leopold, M & Roberts, M, 2001. The radar signatures and age of periglacial slope deposits, central highlands of Germany. *Permafrost and Periglacial Processes,* 12, 379-87.

Watters, M, 2006. Geovisualisation: an example from the Catholme Ceremonial Complex. *Archaeological Prospection,* 13, 282-90.

Webber, M, 2007, On-site discussion, Flag Fen, personal communication.

Webber, M, 2008. On-site discussion, Flag Fen, personal communication.

Webster, C J, *South West archaeological research framework: Recent work on the Bronze Age*, Available on-line at: http://www.somerset.gov.uk/somerset/cultureheritage/heritage/swarf/themes/l baia/ [Accessed: 19.04.2007].

Weller, A, Nordsiek, S & Bauerchose, A, 2006. SIP- a geophysical method for archaeological prospection in peatlands. *Journal of Wetland Archaeology,* 6, 105-25.

Weston, D G, 2001. Research Notes: Alluvium and geophysical prospection. *Archaeological Prospection,* 8, 265-72.

Weston, D G, 2004. The influence of waterlogging and variations in pedology and ignition upon resultant susceptibilities: a series of laboratory reconstructions. *Archaeological Prospection,* 11, 227-35.

Wheatley, D & Gillings, M, 2002. *Spatial technology and archaeology: The archaeological applications of GIS.* London: Taylor and Francis.

Wheatley, D, 2005. *Unpublished teaching materials from course on digital image processing* at: Southampton University.

Wilson, C, Davison, D & Cresser, M, 2008. Multi-element soil analysis: an assessment of its potential as an aid to archaeological interpretation. *Journal of Archaeological Science,* 35, 412-24.

Guide to the data supplied with this thesis

Two DVDs are provided with this thesis.

DVD 1 contains the raw radar data and the .jpeg format outputs provided by the software following processing. The intermediary files generated by this process are very large, and require specialist software to access, so have not been included.

The data is arranged by Survey Area and then by Site, and with folders for each antenna used, and within those a folder containing the raw radargrams and associated header files, and a folder containing numbered .jpeg images of each timeslice produced.

DVD 2 contains the rest of the digital site archive. It follows the same structure as above, with folders for each area and then each site. The site folders are structured as follows:

SITE: the primary folder for each archive. Contains all other folders, plus the ESRI Map document for the site GIS.

Geophysics: Contains the following folders:

Raw EM: contains the spreadsheets used to prepare the EM data for use in GEOPLOT

GRID: contains a folder for each technique used, which will in turn have all the GEPLOT generated .grd files for each survey

COMP: contains a folder for each technique used, which in turn has .cmp files, composited files of the grid data, for each step in the processing

MESH: contains a folder with .plm files – these mesh files are used to reconstruct the various .grd files in the right order to make the .cmp files used for data processing

Shapes: Contains multiple folders, each containing a group of related shapefiles, for example the various dGPS surveys of a site, or the interpretation layers. Also contains a folder called 'geophysics' but this contains the outputs from the conversion script,

making the GEPLOT .cmp files into ESRI raster datasets. Within this folder is a sub-folder called 'rectified', which houses the rectified dataplots. Selected rectified radar outputs might also be placed in here.

Images: Contains, in named folders photographic records of survey and excavation, and any scans, plans or drawings associated with the site.

Tables: Contains any tables or spreadsheets associated with this site, sensibly named, such as the record of the digests for the ICP studies, or downloads of data from the dGPS.

OSData: Contains shapefiles and licenses for data downloaded from Digimap under license that are used in the base maps in the GIS.

Appendix A: Geophysical data processing logs

This Appendix contains descriptions of all of the corrections and enhancements applied to the geophysical data collected during the project.

A1. The Sweet Track

Canada Farm

Canada Farm RM15/MPX A
The data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm RM15/MPX B
The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm RM15/MPX C

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm RM15/MPX D
The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm RM15/MPX E

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm RM15/MPX F

The data was High Pass Filtered to remove the gradient and enhance the linear anomaly. An 8x8 window was used, with Gaussian weighting. The gradient 'real' but interferes with the optimal display of the anomalies in the data.

Canada Farm FM36

The data showed some spiking but overall had a narrow range of values so was not clipped. The data was despiked twice with a 3x3 window, a threshold of 3 standard deviations and using the mean value as the replacement value. The data then had the zero mean traverse function applied to remove some striping and drift within the data. The data was then further processed to smooth it for visual appeal. Firstly it was Low Pass Filtered with a 2x2 window and Gaussian weighting, then it was interpolated to 0.25m traverses to equal the in-line sampling intervals.

Canada Farm EM38

The data was downloaded from the instrument into a text file using the software supplied by the manufacturer. This was then edited in a text editing program to remove the header data and turn spaces into commas, making it effectively a .csv document. This document was then opened in MS Excel and the quadrature and inphase responses were separated into different files. The two resulting files were then imported into GEOPLOT. The raw grids that resulted from this then had to be edited to correct the traverse mode as GEPLOT assumes a parallel traverse when the data has been collected zig-zag. This is done by selecting 'invert traverse mode' from the edit menu for each grid, before creating composites.

As previously stated, the EM38 logs two pieces of information, the quadrature component of the signal, and the inphase component. The quadrature is a measurement of the conductivity of the soil, and is expressed in milli-siemens per metre. The inphase is a measurement of magnetic susceptibility as is therefore a ratio and expressed in SI units.

The data needed no processing to make the features visible; in the in-phase data there is very little variation and the range of values is very narrow. The conductivity had few erroneous readings in it to distort the images. Processing the data was therefore unnecessary as the meaningful variations are apparent in the 'raw' data.

Horizontal, Quadrature Phase
The data is presented unprocessed.

Horizontal, Inphase
The data is presented unprocessed.

Vertical, Quadrature Phase
The data is presented unprocessed.

Vertical, Inphase
The data is presented unprocessed.

Canada Farm 250 MHz Radar Survey
Data Capture:

Time window:	65ns
Samples:	580
Trace Interval:	0.05m

Data processing:

Scans per mark:	32
Number of slices:	50
Thickness in samples:	25
Thickness in ns:	2.8

Samples start: 21

Samples end: 580

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 21

The data was processed in two batches, the forward runs and the reversed runs (as the data was collected 'zigzag'. The first 30 datasets were then combined. This is to remove in-line aliasing caused by slight variations in antenna positioning on the different runs. The last 20 were omitted following examination as the signal had become too attenuated to show useful information.

Canada Farm resistivity inversions

The best results for this site were obtained by forcing the model blocks to be ½ the unit spacing (1m, the sample interval) and having no smoothing or robustness applied to the inversion.

10 transects were modelled, 5 in each direction across the same grid the other surveys were carried out over. The field values had to be multiplied by ten to run the inversions as the model has difficulties resolving resistances close to zero, so the ohms values given in the figure are not absolute, but allow a comparison of the different subsurface resistivity.

The Old Peat Works

Peat Works RM15/MPX A

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works RM15/MPX B

This grid contained a spike (762.5 ohms) right at the edge of the grid which the despike algorithm would not have removed; this was manually replaced with the

mean value of the dataset. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works RM15/MPX C

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered using enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works RM15/MPX D

This grid contained a spikes right at the edge of the grid which the despike algorithm would not have removed; these were manually replaced with the mean value of the dataset. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works RM15/MPX E

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works RM15/MPX F

The data was initially despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works FM36

This dataset was problematic. The metal fence at the eastern edge of the grid caused more interference than was expected, possibly due to the generally low magnetic

contrasts observed in the peat soils. The readings influenced by the fence had to be stripped out; this was accomplished by use of the search/replace function, replacing all values in the last 2.5m of the grid (working west-east) with dummy values. The rest of the grid had a number of strong ferrous spikes that the despike algorithm did not sufficiently reduce, so the data was first clipped to +/- 3 standard deviations, which removed the spikes. There was also some drift in the data so this was removed with the zero mean traverse function. The data was then interpolated twice in the y direction (between traverses) to make the resolution equal, and to smooth the data for visual appeal. Low Pass Filters were tried to further smooth the data, but they smeared the remaining spikes and some of the stronger features, so this processing was not retained.

Peat Works EM38 Vertical, Quadrature

The EM dataset was also affected by the presence of the fence as it was made from conducting and magnetic materials. The first step in processing this data was to remove the impact of the fence by replacing the last three values / meters (running west-east) of each run with dummy values. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies. An 8x8 window was used, with Gaussian weighting.

Peat Works EM38 Vertical, Inphase

Only the last 2 meters/ readings of each run were affected by the fence in the inphase data, so these were replaced with dummy values. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value.

Peat Works EM38 Horizontal, Quadrature

The last 3 meters/ readings of each run were affected by the fence in the inphase data, so these were replaced with dummy values. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value. Then the data was High Pass Filtered to enhance any anomalies.

Peat Works EM38 Horizontal, Inphase

The last 3 meters/ readings of each run were affected by the fence in the inphase data, so these were replaced with dummy values. The data was then despiked using with a 3x3 window with a threshold of 3 standard deviations and replacing with the mean value.

Peat Works GPR 250MHz Radar Survey

Data Capture:

Time window: 128ns

Samples: 520

Trace Interval: 0.05m

Data processing:

Scans per mark: 32

Number of slices: 30

Thickness in samples: 30

Thickness in ns: 3.4

Samples start: 22 forward /21 reverse

Samples end: 580

Cut parameter: squared amplitude

Cuts per marker: 2

0ns offset type: constant

0ns offset: 22 forward/ 21 reverse

A2. Flag Fen

Area 1

Bartington DualGrad601 Gradiometer survey

The data was 'desampled' for more ready comparison with the data collected in the resistivity and EM surveys, using the interpolation function, and changing the function to linear-shrink, once in the y direction, and three times in the x direction. This approximates to what would have been gathered with a 1x1m sampling interval. The data was then despiked using the following settings:

Twice with a 1x1 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Once with a 2x1 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Twice with a 2x2 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Five times with a 3x2 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Once with a 4x1 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Once with a 4x2 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

Twice with a 3x2 reading window, a threshold of +/-3SD and replacing with the mean of the adjacent cells.

In a separate set of processes, the raw data has also been clipped and interpolated to make more of the anomalies visible despite the presence of large ferrous spikes distorting the dataset. The processes applied were as follows:

The data was clipped (using the clip function) about the mean to 3 standard deviations to attempt to reduce the influence of the ferrous material on the image statistics. Experimentation proved this to have a more satisfactory result than using the despike tool. It was then interpolated in the y direction twice to increase the resolution of the image and 'smooth' its appearance, making it easier to interpret.

Geoscan Research RM15/MPX15 survey
Due to the very dry surface at the time of the survey, the raw data are very noisy.

RM15/MPX A (0.25m):
Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.
The despike tool was then used twice with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies.

RM15/MPX B (0.5m):

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.

The despike tool was then used once with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies.

RM15/MPX C (0.75m):

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.

The despike tool was then used once with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies.

RM15/MPX D (1m):

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.

The despike tool was then used twice with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies.

RM15/MPX E (1.25m):

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.

The despike tool was then used three times with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

The dataset was then clipped again as above. Due to the dimensions of the array and problems with ground contact, this layer of the data proved to have a number of high resistance spikes that tend to occur at the edges of the area surveyed (i.e. as the array moves onto footpaths and it is hard to get the electrodes into the soil). Spikes at the edge of a survey are harder to remove due to how the filters function.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies.

RM15/MPX F (1.5m):

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by poor electrode contacts in drier parts of the soil. Clipping alters the image statistics and makes the despike tool more effective in some cases.

The despike tool was then used twice with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Finally a high pass filter was applied with an 8x8 window and uniform weighting to suppress background variations and enhance the visibility of potentially archaeological anomalies. In many ways this layer was as 'spiky' as E but the anomalies were weaker, so further processing would have stripped out features as well as the spikes, hence the fewer attempts to despike and clip this layer.

Geonics EM38B Vertical survey

Quadrature:

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by the presence of highly conductive objects (probably buried modern ferrous material) in some areas of the survey.

The despike tool was then used once with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Inphase:

Clipped about the mean to +/- 3SD to reduce the influence of spikes in the data caused by the presence of highly conductive objects (probably buried modern ferrous material) in some areas of the survey. Highly conductive objects can cause 'signal leak' into the inphase component of the response, causing spikes in the resulting image.

The despike tool was then used once with a 3x3 window, a threshold of +/- 3SD and replacing the spikes with the mean of the adjacent cells.

Resistivity Inversions

The best results for this site were obtained by forcing the model blocks to be ½ the unit spacing (1m, the sample interval) and applying a robustness constraint; this allows for quite abrupt changes in the resistance of the material in the subsurface. On this part of the site the peat is very dry at the immediate surface but seems to be well hydrated immediately below this.

250MHz Radar Survey:

Data Capture:

Time window:	128ns
Samples:	520
Trace Interval:	0.05m

Data processing:

Scans per mark:	32
Number of slices:	30
Thickness in samples:	20
Thickness in ns:	4.9
Samples start:	31
Samples end:	350
Cut parameter:	squared amplitude
Cuts per marker:	4
0ns offset type:	constant

0ns offset: 31

500MHz Radar Survey

Data Capture:

Time window: 49.2ns

Samples: 512

Trace Interval: 0.05m

Data processing:

Scans per mark: 32

Number of slices: 40

Thickness in samples: 25

Thickness in ns: 2.5

Samples start: 22

Samples end: 512

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 22

Mosaic Corrections- GPR Survey

There are mosaic errors, that is, zones with different background signal responses and anomaly strengths, (Goodman 2008b, Sections XV, subsections A & E) in this dataset caused by the survey being done on different days, by different operators and with differing battery strengths. A number of the suggested processes for dealing with these have been attempted, and the most satisfying result has come from applying a filter at the stage immediately after slicing the data, but before producing and gridded datasets that creates a zero mean for each line of data. This function has a threshold based on a certain % of the values in a line. The most satisfactory results have been with it set to ignore the top 10% of all of the values when calculating the average. This means anomalies (and especially linear anomalies in the survey direction) are more likely to be preserved, and a better background match achieved. It is similar to the zero mean traverse function used in GEOPLOT to correct for drift. This has not

totally removed the mosaic problems within the dataset, but allows a greater appreciation of the relative strengths of the anomalies.

Area 2

RM15/MPX Separation A- 0.25m

This data showed a skewed histogram with a very wide range of readings (7.3 to 203.5 ohms), probably due to poor probe contacts and very dry conditions at the immediate ground surface in places. This wide and skewed histogram means there is quite a large standard deviation, so the data set was clipped to +/- 3 Standard Deviations (SD), that is to a minimum of 5.53 and a maximum of 53.87ohms.

The data was then despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading.

Further despiking and smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

RM15/MPX Separation B- 0.5m

This data shows a very constricted histogram, with obviously rogue high values skewing the data, again likely to be due to poor probe contacts in dry conditions. As before, the dataset was clipped to +/- 3 SD, that is, to a minimum of -8.76 and a maximum of 30.412ohms (this does not mean the data has negative values, just that the mean is closer to zero).

The data was then despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

RM15/MPX Separation C- 0.75m

This data showed similar issues with a skewed histogram as before, with a minimum value of -2.5 and a maximum of 148.9 (though a mean of 6.99 ohms). The negative values are a result of probe contact problems. This is not an issue for processing/

displaying the data in Geoplot, but does need correction before resistivity inversions are made (see below).

The data was clipped to +/- 3SD to correct the histogram, to a minimum of -10.41 and maximum of 24.39.

The data was then despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

RM15/MPX Separation D- 1.0m

This data exhibited a very normally distributed histogram, and an SD of less than 1ohm, so clipping was not necessary. The data was despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading, to deal with occasional spikes caused by poor probe contacts.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

RM15/MPX Separation E- 1.25m

This data exhibited a very skewed histogram, and so was clipped to +/- 3 SD to bring the range to more normal parameters before applying other corrections. This meant a minimum of -19.75 and a maximum of 28.79 ohms.

The data was then despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading.

There were still problems with large spikes on the edges of the survey area; due to edge effects, these are not always effectively removed with the despike function, so the data was again clipped to +/- 3 SD, with a minimum of 0.61 and a maximum of 7.27 ohms. This has the added benefit of removing negative values (caused by poor probe contacts) to be eliminated.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

RM15/MPX Separation F- 1.5m

The data was again skewed, due to more general problems with probe contacts becoming more obvious as the array dimensions increase. It was clipped to +/- 3 SD to normalise the histogram, i.e. to a minimum of -8.8 and a maximum of 15.74.

The data was then despiked with a 1x1 reading window, a threshold of 2.5 SD and replacing the value with the mean reading.

There were still problems with large spikes on the edges of the survey area; due to edge effects, these are not always effectively removed with the despike function, so the data was again clipped to +/- 3 SD, with a minimum of 2.06 and a maximum of 4.64 ohms. This has the added benefit of removing negative values (caused by poor probe contacts) to be eliminated.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

Bartington Dual Grad 601 survey

The data was downloaded from the instrument using software supplied by the manufacturer, exported to GEOPLT and reconstructed there for processing.

There was some modern metal debris in the field, so the first task was to remove an off the scale anomaly corresponding to this that was masking the other features in the plot. The data was there for clipped to +/- 3SD, i.e. a minimum of -153.39 nT and a maximum of 148.05 nT.

Despiking was attempted using a filter, but due to the 1m x 0.125m reading intervals this instrument produces, the correct window for effectively removing these spikes could not be constructed in the software. The data was instead clipped again to +/- 3 SD of the new data distribution, i.e. a maximum of -23.41 and a maximum of 17.00.

At each stage, the plots were checked and compared to ensure that only noise was being removed, and no archaeologically interesting anomalies were being stripped out.

The data was then despiked with a 4x2 reading window, 2.5 SD threshold and mean replacement of any values outside the threshold.

A zero mean traverse filter was applied to remove the influence of a metal fence that gets incrementally closer to the western edge of the survey area.

The data was then interpolated to 0.5 x 0.125 m cells to smooth the appearance and aid interpretation.

EM38 electromagnetic survey

Vertical, Quadrature Phase

This component of the EM data is a measurement of the conductivity of the soil, in milli-siemens/ metre (mS/m). The data is downloaded from the Polycorder data logger with software provided by the manufacturer, then split into the two phases in a spreadsheet package. It is then imported into GEOPLOT, and, due to the way the data is collected and stored, the traverse mode is inverted to correctly order the data.

This data again showed a skewed histogram, with some negative readings caused by the presence of very conductive modern ferrous rubbish on some parts of the survey area. To correct for this, the data was clipped to +/- 3 SD, i.e. to a minimum of 25.57 and maximum of 44.76 mS/m.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

Vertical, Inphase

This component of the EM data is a measurement of the magnetic susceptibility (MS) it is measures in the field as parts per thousand, relative to the site 'background' established at magnetically quite spot where the instrument is tuned, prior to survey. The data is downloaded from the Polycorder data logger with software provided by

the manufacturer, then split into the two phases in a spreadsheet package. For this dataset, we trialled multiplying the ppt values by 1000 to give parts per million, as whole numbers are supposed to be easier for GEPLOT to handle. It is then imported into GEPLOT, and, due to the way the data is collected and stored, the traverse mode is inverted to correctly order the data.

This data was relatively unproblematic, with one or two spikes caused by very conductive materials on the ground surface (when highly conductive or magnetic objects are encountered the effect on the EM field can be so strong it appears in the 'out of phase' signal as well; this is sometimes called signal leak, where a conducting object appears in the Inphase data and vice versa). These were removed with a despike filter of 3 x 3 readings, a threshold of 3 SD and replacing spikes with the mean value.

The data also showed a step in the values, due to instrument drift. This was corrected by applying a zero mean traverse to the dataset.

Further smoothing processes were trialled but either removed features, or produced artefacts in the plot which could be misinterpreted.

Mala GPR 500 MHz survey

Data capture:

Time window: 31ns

Samples: 512

Trace Interval: 0.05m

Data processing:

Scans per mark: 32

Number of slices: 30

Thickness in samples: 25

Thickness in ns: 1.51ns

Samples start: 21

Samples end: 512

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 21

Mala GPR 250 MHz survey

Data capture:

Time window: 128ns

Samples: 520

Trace Interval: 0.05m

Data processing:

Scans per mark: 32

Number of slices: 30

Thickness in samples: 25

Thickness in ns: 6.2ns

Samples start: 26

Samples end: 512

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 26

Mosaic error corrections were applied as discussed above.

A.3 Dartmoor

Yellowmead Down

RM15 resistivity survey

The presence of the leat and the location of the remote probes caused some grid matching problems for this survey. As far as possible the values before and after moving the remote probes were matched in the field, but this proved impossible for grids 5 and 10, the far side of the leat so it was decided to move the probes to the far side of the leat along with the grids.

The data was also quite variable due to some instances of poor probe contacts; especially in grids 5 and 10 which proved to have a markedly different character to the rest of the survey.

The data was first clipped to +/- 3 standard deviations (SD) about the mean to make the raster statistics less skewed by extreme values. It was then despiked twice with a 2 x 2 reading window and a threshold of +/- 3 SD from the mean. Values outside this were replaced with the mean value of the readings covered by the window. The despike was applied again with a 1x1 window and the same thresholds.

Despite precautions taken in the field, the grids still showed some variation in background values, so they were edge matched, as follows:

Grid 2 was matched along the top, right then bottom edges, grid 7 was matched along the top and bottom edges, grid 3 was matched along the bottom edge, grid 8 was matched along the bottom edge, grid 3 was matched along the right edge, grid 4 was matched along the right edge and the bottom edge and grid 9 was matched along the bottom edge.

The data was then further despiked, now the image statistics had been normalised, with a 1x1 reading window and the same thresholds as before, twice.

Finally, the data was high pass filtered with a 5x5 reading window using uniform weighting.

FM36 gradiometer survey

The data showed some spiking so was first clipped to +/- 3SD. There was also some drift evident and mismatches between grids surveyed at different time of the day so the zero mean traverse function was applied, which has the effect of normalising the data around 0.

Some spiking was still evident but the clip function had compressed the statistics enough to apply the despike tool. This was applied once with a 2 x 2 reading window

with a +/- 3SD threshold, replacing values with the mean, and then again with the same window and replacement but with a +/- 2.5 SD threshold.

The data still had some issues with high values near the edges of the grid so was again clipped to +/- 5nT (absolute); as most of the archaeological features seemed to be within this range and were being obscured other anomalies in the image, due to problems negotiating the stones of the circle. There were also discontinuities at the start of traverses due to heading errors; these were corrected by deducting 0.75nT from the first 7 readings of grids 6-10 and the first 5 readings of grids 1-5.

Finally to equalise the image cell intervals and improve the visual appearance the data was interpolated twice in the Y direction.

EM38 electromagnetic survey
Vertical, Quadrature Phase
This data presented issues to do with instrument drift and instability; some grids showed drift due to the warming or cooling of the instrument, and some showed distinct jumps in values probably due to slipping of the control dials for balancing the instrument. There were also mis-matches between grid edges.

Firstly the data was desloped, as follows.
Grid 1 was pivoted on the bottom edge with a far edge bias of +0.25, grid 2 was pivoted on the top edge with a far edge bias of +1, grid 3 was pivoted on the bottom edge with a far edge bias of -1.25, grid 8 was pivoted on the top edge with a far edge bias of -1, grid 7 was pivoted on the top edge with a far edge bias of -1 and grid 4 was pivoted on the bottom edge with a far edge bias of -1.

The grids were then edge matched. Grid 1 was matched on its right side and grid 9 was matched on its left side.

The data was the despiked with a 1x1 reading window, a threshold of +/- 2.5 SD and with the mean value being used as the replacement.

Grid 3 still showed some strong steps in the data. This was corrected by adding +0.4 bias to the central north/ south section of the grid. It was then matched to the rest of the survey by adding a -0.3 bias to the whole grid. Another strip of 'jumped' response was the last line surveyed of grid 5. A bias of +1 was added to this block of data. Finally the data was despiked again, with the same settings.

Vertical, Inphase

This data had some pre treatment prior to importing it to GEOPLOT3, to make the data easier to handle and to make the units more useful. Before it was imported, the raw field measurements were multiplied by 1000 in a spreadsheet package to convert them from ppt to ppm. This has an additional affect of shifting the data to values above 0, as values between 0 and 1 in Geoplot can be truncated to 2 decimal places.

The data had one large spike right at the edge of the image (caused by a metallic tape measure); this was manually replaced with the rough average of the dataset, -20 ppm.

This data showed a large amount of drift and discrepancies between grids; a zero mean traverse was applied to correct for this. The data was then despiked with a 3x3 reading window, a threshold of +/- 3SD and replacing the spike values with the mean.

500 MHz Radar Survey

Data capture:

Time window: 67ns

Samples: 512

Trace Interval: 0.02m

Data processing:

Scans per mark: 50

Number of slices: 30

Thickness in samples: 35

Thickness in ns: 4.6ns

Samples start: 3

Samples end: 512

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 4

Mosaic Corrections

There are mosaic errors, that is, zones with different background signal responses and anomaly strengths, (Goodman 2008, Sections XV.A & E) in this dataset caused by the survey being done on a number of different dates, sometimes weeks apart and therefore under different conditions. A number of the suggested processes for dealing with these have been attempted, and the most satisfying result has come from applying a filter at the stage immediately after slicing the data, but before producing any gridded datasets that creates a zero mean for each line of data. This function has a threshold based on a certain % of the values in a line. The most satisfactory results have been with it set to ignore the top 50% of all of the values when calculating the average. This means anomalies (and especially linear anomalies in the survey direction) are more likely to be preserved, and a better background match achieved. It is similar to the zero mean traverse function used in GEOPLOT to correct for drift. This has not totally removed the mosaic problems within the dataset, but is comparable, in terms of the visible anomalies as processing each block of readings

collected on the same day separately (which has also been undertaken, but not included here for the sake of brevity).

Drizzlecombe

RM15 resistivity survey

The data showed a very high initial range, from 314.5 to 1470 ohms, though this seems largely due to one two obvious 'spikes' that seem to be a probe contact issue.

There are also two bands of apparently anomalously low values that appear to be spatially constrained. This is also likely to have been some sort of probe contact issue, perhaps caused by using the fasted logging speed on the RM15, with the value not having adequate time to settle in lower resistivity areas, giving falsely low results in patches. These proved resistant to the despiking tools so the data was first clipped to +/- 3SD about the mean (a maximum of 622.002 and a minimum of 394.89). This dealt with the majority of the low value spikes, but the higher ones remained, cut off at the new maximum, due to the string skew they created in the histogram for the data. These were also resistant to the despike tool and so the search/ replace function was used to replace all values from 621 to 623 ohms with the new average for the dataset, 508.398. Both of these processes were checked to ensure no features were being stripped out.

These two processes normalised the histogram to the point that a further despike, with a window of 1x1 reading, a threshold of +/- 3SD and replacing with the mean value was able to deal with any residual spikes, apart from a few on the northern edge of grid 2. Due to their position, the despike filter could not reduce them but their value was within the 'normal' range for other areas of the grid so a blanket search & replace would have lost data. In the end these were left alone as they did not detract from the interpretation of the data, and any attempt to remove them risked removing meaningful variation as well.

There was a slight mismatch between grid 1 and grid 2 so the edge-match tool was used along the join, matching grid 2 to grid 1. This was due to having to remove the remote probes between grids, and not being able to obtain an adequate match in the field.

The plot shows a general change from higher resistances upslope to lower ones at the western edge of grid 2. In order to try to bring out any smaller scale features being masked by this, a high pass filter was applied using an 8 x 8 reading window and uniform weighting.

FM36

This data showed a very low range of initial values, from -6.68 to +11.32 nT. There was also a distinct background change between the two grids, likely to be cause by diurnal shift between survey times. The grids themselves show little in the way of drift, just a large step-change between them. There was also some slight striping evident in the data where the instrument had perhaps been carried slightly differently on one or two lines.

A zero mean traverse function will both deal with the striping, to some extent, and solve the edge mismatch. No linear features in the traverse direction were expected, so the filter was applied using the default settings.

Once this had been done a number of 'start of line' errors appear quite consistently in the data, particularly in grid 2, due to slight changes in the height of the instrument or the heading as the operator started each traverse. These were corrected in two stages by deducting 0.5 nT from the first 5 values of each traverse for part of the survey, and then a further -1 nT for the first 5 readings for each traverse in grid where the problem was stronger. In between the two steps the data was despiked with a 1 x1 reading window, +/- 3SD threshold and the mean as the replacement value. This didn't remove the defect, but did effectively despike the data. The data only needed minimal de spiking and no clipping as the histogram was well balanced with very few outlying values.

The data still appears to be very noisy, but the range of values has reduced to -6.19 to +5.5 with a standard deviation of less than 1. This means that there is very little magnetic variation in the soil so the survey will be more sensitive to the gait of the operator and encoding noise in the signal as it is converted from a continuous value to blocks of data. Various filters were employed to attempt to improve the signal to

noise ratio, including a periodic filter to remove the gait effect, but none of these measures resulted in significant enhancement of the data.

As such, the data has simply been interpolated in the x direction to give an overall resolution of 0.25 x 0.25 readings/m, and a low pass filter with a 2 x 2 reading and uniform weighting applied to smooth the data and enhance its' visual appeal.

EM38

The EM38 data required a lot of correction due to problems with drift/power supply in the instrument which lead to stepped changes in the data. This was more of a problem in the vertical 1 x1 m survey than in the horizontal 0.5 x 0.5m survey. Details of the corrections for this problem are described in detail below.

Horizontal, Quadrature Phase

This data set showed some unusual drift/ reading jumps, which is interesting as it was recorded at the same time as the inphase data discussed below. There were obvious steps in the data, but some of the occurred mid-line, which causes issues for any processing that relies on using functions across a whole traverse. There also appeared to be a real increase in conductivity in the western long edge of the grid; this also ruled out using any averaging of traverses in the processing as it would remove this anomaly.

Unfortunately one of the most obvious 'jumps' in readings occurred within a line of the intersection of the grids, and so needed correcting before any edge matching could take place. As such, the final line of Grid 2 (60) and part of the one above it (59) were selected and averaged, this average compared to the Grid average, and adjusted with the add function (+1). The data was then edge matched on the bottom of Grid 2. Spikes in the data were then removed using the despike tool with a 3x3 window, a threshold of +/- 3SD and using the mean as the replacement value.

Various filters were tested to enhance the appearance of the dataset and emphasise any anomalies. Usually, high pass filtering is used with electrical data to show areas of rapid change, which are more likely to be archaeological than gradual background changes. However, this filter confused the appearance of the data and removed the

conductivity change noted in the western edges of the grids. Instead, the data was subjected to a low-pass filter to smooth its appearance for presentation, while preserving the gradual change discussed above. This filter used a 2x2 reading window.

Horizontal, Inphase

On initial examination this data set had a number of problems. Drift was evident in both of the grids and there did appear to be some step changes. The overall range of the data was limited (-0.6- +1.23 ppm), making these problems appear more pronounced.

The drift issues needed to be tackled first. This was achieved by taking the average for each grid individually and choosing which grid edge lay closer to the mean of the grid. The closest line to this edge was then averaged, along with the far edge to determine what should used as the far edge bias in a deslope correction.

Grid 1 (as per grid layout shown in figure 1) was pivoted on the top edge with a far edge bias of +0.86. Grid 2 was pivoted on the top edge with a +0.69 far edge bias.

The edge matching process was then applied to correct for the difference between the two grids, but this was found to make the slight steps in the data far more pronounced. Instead, the grids were matched by taking the new mean of each grid, and then adding 0.39 to Grid 1 with the add function to align the means. This produced a roughly normally distributed histogram for the whole image, though there were some slight steps in the data. The results compared favourably with the edge matched ones.

The data was then despiked with a 3x3 reading window, a threshold of +/-2.5 SD and using the mean as the replacement value.

Following this, a discontinuity between the grids remained apparent. The edge matching (Grid 2, bottom edge) was re-tried, this time with satisfactory results.

Further processes were attempted to remove the slight steps in the data but they either introduced false 'features' or processed the existing ones away.

Vertical, Quadrature Phase

This data suffered from much more severe 'stepping' than the horizontal data sets; the steps were more obvious, had more of an effect on the overall distribution of values (therefore potentially masking anomalies). The first step was, therefore, to remove those steps.

A processed was developed which involved a more lengthy version of the corrections applied to the Horizontal quadrature phase data to correct the data to the point where it could be edge matched: each 'block' identified by visual examination of the shade and trace plots, was selected and averaged and this average compared to the overall grid average. Each data block then had a blanket positive or negative bias added; the difference between the two averages. The detailed history of this is preserved in the files themselves and by the author but is not repeated here for brevity. Though the general pattern of values suggested an underlying drift, the steps in the data made correction with the deslope tool impossible.

Following this process, the data was despiked with a window of 3x3 readings, a threshold of +/- 2.5 SD and using the mean as the replacement value. No edge matching was needed as the 'step corrections' described above produced a good match between the two grids.

However, despiking the data reduced the overall range of the data, which allowed some steps to become more obvious as the range narrowed. These were tackled again, using the process described above; usually on single lines of data rather than whole blocks. It seems likely that the 'blocks' dealt with in the first round of step corrections all had an emphasised 'first line' that was not adequately reduced by the first correction.

Various filters were tried to better visualise the data but they all confused the image, potentially generating processing anomalies, so it was decided to process or enhance the data any further.

Vertical, Inphase

This data suffered from much more severe 'stepping' than the horizontal data sets; the steps were more obvious, had more of an effect on the overall distribution of values (therefore potentially masking anomalies). The first step was, therefore, to remove those sudden changes. A process was developed which involved a more lengthy version of the corrections applied to the Horizontal quadrature phase data to correct the data to the point where it could be edge matched: each 'block' identified by visual examination of the shade and trace plots, was selected and averaged and this average compared to the overall grid average. Each data block then had a blanket positive or negative bias added; the difference between the two averages. The detailed history of this is preserved in the files themselves and by the author but is not repeated here for brevity. Though the general pattern of values suggested an underlying drift, the steps in the data made correction with the deslope tool impossible.

Once the steps were reduced (the process could not entirely eliminate them) it was possible to edge match the grids, along the bottom of Grid 2. Finally, the dataset was despiked with the despike tool using a 3x3 window, a threshold of +/- 2.5 SD and using the mean as the replacement value.

Various filters were tried to better visualise the data but they all confused the image, potentially generating processing anomalies, so it was decided to process or enhance the data any further.

500 MHz GPR Survey

Data capture:

Time window: 57

Samples: 927

Trace Interval: 0.02m

Data processing:

Scans per mark: 40

Number of slices: 30

Thickness in samples: 25

Thickness in ns: 1.5

Samples start: 46

Samples end: 800

Cut parameter: squared amplitude

Cuts per marker: 4

0ns offset type: constant

0ns offset: 46

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Resistivity Survey (RM15 Twin Probe, 0.5m)

The data showed a very large range and broad histogram, so was initially clipped at +/- 942.83 ohms, and then despiked with a 1x1 reading window and a threshold of +/- 3 SD, replacing with the mean.

Following this, the data was High Pass Filtered with an 8x8 window and uniform weighting, and was then interpolated twice to smooth the data.

Gradiometer Survey (FM36)

The data showed a lot of noisy variation, so was strongly clipped to +/- 37.5nT, and then despiked with a 1x1 reading window and a threshold of +/- 3SD, replacing with the mean. It was then interpolated to smooth the data and further reduce the noise to look for any anomalies, but proved generally too noisy.

EM38 Survey
Vertical inphase response

The survey was affected by instrument drift between grids, so the edge match tool was used to match grid 2 along the bottom edge, grid 4 along the left edge and grid 3 along the top edge; bring all grids to the same zero-point as grid 2 (the northeast quadrant).

The data was then despiked twice, with a 1x1 window, a threshold of +/- 3SD and replacing with the mean.

Vertical quadrature response

The survey was affected by instrument drift, so the deslope tool was employed on grid one (the northwest quadrant) along the top edge to apply a gradual bias of 0.95mS/m over the grid. The data was then edge matched on the top of grid 4, and finally despiked with a 1x1 reading window, a threshold of +/- 3SD and replacing with the mean.

500MHz Radar Survey

Data capture:

Time window:	52
Samples:	512
Trace Interval:	0.02m

Data processing:

Scans per mark:	32
Number of slices:	30
Thickness in samples:	25
Thickness in ns:	2.5
Samples start:	34
Samples end:	512
Cut parameter:	squared amplitude
Cuts per marker:	4
0ns offset type:	constant
0ns offset:	34

The resulting slices were auto-gained and then a low-pass filter was applied as the data was quite noisy.

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Gradiometer Survey (FM36)

There were some stagger errors in the data as it was collected by zig-zag survey. These were corrected with the de-stagger tool, with a shift of two positions, acting on even lines.

The data was then clipped to +/5 nT absolute as there was a large amount of ferrous rubbish in a fence-line along the southern edge of the survey.

The data was then despiked with a 1x1 reading window, a threshold of +/- 3SD and using the mean as the replacement value.

Finally, the data was interpolated once in the x direction to achieve the same resolution as the in-line measurements, and smooth the appearance.

Appendix B: Specialist flint report for Yellowmead Down Excavations by Jane Marchand

This report was kindly supplied by Jane Marchand from the DNPA archaeology service, for find F001 from Trench 4 at the Yellowmead Down excavations. For a sketch of the find, see Figure 11.37.

Flint artefact from Yellowmead

Tool blank and raw material

Flint flake measuring 34mm by 22mm, features include butt, bulb of percussion and bulbar scar.

The rough surface of the cortex present suggests this is a flint from a primary chalk source, it is of good quality material with a fairly fine grained texture and a medium lustre.

Retouch

It is retouched at both the distal end and the right lateral side, this retouch is deep/long as opposed to shallow/short, extending inwards so that the retouch scars cover more than just the edge margin, the angle of retouch is between low and semi abrupt. The angle of retouch is low enough to be a knife and yet not so low as to negate it being a scraper.   It is off a good quality worked by an experienced knapper.

At the proximal end a spall of flint has been deliberately or accidentally detached, this has blunted that section of the left edge, and the cortex on that edge has a similar blunting effect. This may be of relevance to the tool function (see below).

Tool classification

Using the Alan Saville scraper typology this is an **extended end scraper**, i.e. an end scraper variant on which the retouch of the distal end is continued laterally down one or both edges without any pronounced angle between the distal and lateral retouch as is the case with end-and-side scrapers (Saville 1981, 132). The spall detachment may have been accidental, and may have come off as the flake was detached from the core. However if the spall detachment was deliberate there are two possibilities.

The first is that it is a **small knife** backed partly by cortex and partly by the spall.

The second possibility is that it is a **composite tool** combining in this case an end scraper and a knife on the same blank. Published lithic reports suggest however that

most composite tools are either end scraper/burin, end scraper/piercer or end scraper/notch. What is clear is that it is not an attempt to make burin, despite the presence of the spall, the morphology of the flake and the cortex on the relevant lateral edge make it an unsuitable burin tool blank.

Chronology

Dating lithic artefacts is a problem unless from secure contexts containing chronologically diagnostic artefacts or other dateable material. Tools to cut and scrape are found in all stone using periods and most scrapers, except thumbnail, are chronologically uninformative stone tools. Nevertheless the discovery of this tool within the ceremonial site at Yellowmead suggests that it most likely dates to the Neolithic/early Bronze Age.

Saville, A, 1981. The flint and chert artefacts (in Mercer, RH Excavations and Carn Brea, Illogan, Cornwall 1970-73). Cornish Archaeology, 20, 1-204.

Archaeological geophysical prospection

in peatland environments

Kayt Armstrong

Dissertation submitted in partial fulfilment of the requirements for the degree 'Doctor of Philosophy', awarded by Bournemouth University

2010

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