Deposit Modelling and Archaeology

Edited by Chris Carey, Andy J. Howard, David Knight, Jane Corcoran and Jen Heathcote

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Cover illustrations

Front: Transect section illustrating Holocene deposits and possible palaeochannels, New Covent Garden Market site, London. Reproduced with the permission of Wessex Archaeology and VINCI St Modwen.

Back: The modelled thickness of the sands and gravels at Grove Farm, Nottinghamshire. Reproduced with the permission of the University of Brighton, Trent & Peak Archaeology and the University of Nottingham.

Museum of London Archaeology field staff using a percussion corer to recover sediment core samples, Bloomberg site, City of London. Reproduced with the permission of Museum of London Archaeology.

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Foreword: Snapshots of reality

Approaches to identifying, recording, and interpreting archaeological remains have moved forward in leaps and bounds over recent years. Traditional and delightfully simplistic notions of the 'site' have been comprehensively challenged. Still perhaps useful to describe places where investigatory events have taken place, the term 'site' no longer carries much meaning for the extensive spreads of archaeological features and deposits that carpet much of Britain and north-west Europe. When interpreting the past, off-site archaeology, time-place patterning, and studies into the social use of space lead the way. In rural areas, landscape archaeology of the kind exemplified by work on Bodmin Moor, Dartmoor, the Somerset Levels, Salisbury Plain, and the East Anglian Fens sets the benchmark. In urban areas the innovative experimental work in Cirencester, Canterbury, Durham, London, and York in the 1990s established new integrative ways of looking at towns and their immediate hinterlands. All focused on the spatially and chronologically continuous nature of the deposits, albeit with evident hotspots in the pattern of original activities and their material residues, and equally evident holes punched through those remains by more recent destructive activities.

Deposit modelling as presented in the case studies and discussions here represents the next phase in capturing, analysing, and presenting snapshots of reality in Britain's rich carpet of archaeological heritage. Using novel data-handling techniques, and powerful computer programmes that earlier generations could only dream of, it is possible to create three-dimensional, scalable, topographically accurate, models of buried features and deposits over wide geographical areas. Much impressive work along similar lines has been done in the Netherlands where relative sea-level change means that vast swathes of prehistoric and later landscape are deeply buried and therefore have to be brought alive through modelling based on borehole data and results from previous excavations. Important contributions from the specialist field of geoarchaeology are evident in the continental work, just as in many of the chapters presented here.

Naturally, deposit modelling places new demands on the way data is collected, the kind of data collected, and the channels by which it is made accessible. The Archaeological Investigations Project (https://aip.bournemouth.ac.uk/index.htm) clearly showed the scale and extent of archaeological work in England, with an average of more than 4000 interventions per year between 1990 and 2010. But despite this dataset being made rapidly available it was rarely used to develop strategic models. Drawing maps with dots was more popular than creating synthetic studies of research potential based on interpretations of past activity across time and space. Negative evidence is just as important as positive evidence in deposit modelling, and quality has to be judged not on the wonders found but the confidence we have in believing what was recorded and equally what was missing.

As the chapters in this volume show, deposit modelling opens doors into new areas of archaeological endeavour for the next generation of research frameworks. For archaeological resource management it allows predictive modelling that can anticipate the sensitivity and value of areas for preservation, and highlight potential as a means of structuring future investigations to maximize returns in terms of information gain and impact. For understanding the past itself there are new ways of mapping the social use of space and analysing human-environment interactions. And for presenting our results to a range of audiences there are exciting new ways of visualizing and experiencing the combined results of existing and ongoing work. This volume is a significant contribution to an important and fast-developing field within archaeology.

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Preface

At one level, 'deposit modelling', in the sense used in this volume, stands as a set of techniques to be used for a specific purpose: namely, elucidating the character and form of deeply buried archaeological remains and ancient topography, especially in the face of development or other threats. The papers presented here make the value of deposit modelling in such situations abundantly clear. Set in a wider context, however, deposit modelling approaches can also be seen as exemplifying what I would argue is one of the most pressing issues in British archaeology today: the need to create general models, and especially ones with a spatial dimension, from the huge volumes of 'point data' which have been collected in recent years.

It is now a truism to say that there has been an explosion of data in English archaeology in recent decades. This has resulted from a variety of causes: the state-funded 'rescue archaeology' programme of the 1960s to 1980s (Thomas 2006); the subsequent 'development-led' archaeology under Planning Policy Note Guidance 16 (PPG 16) on *Archaeology and Planning* (Department of Environment 1990) and its successors; state-funded survey programmes such as the National Mapping Programme (Horne 2011; Historic England 2018); the compilation of local authority Historic Environment Records (HERs, formerly known as Sites and Monuments Records, SMRs) (Fraser and Newman 2006); the Portable Antiquities Scheme (PAS 2017); and the advent of new remote sensing techniques such as LiDAR and large-scale geophysical surveying (English Heritage 2010; and see papers in Cowley (ed) 2011).

In short, we now have vastly more data than we did fifty years ago, or even thirty or twenty years ago. There is no universally accepted definition of 'big data'; however, if one takes the size of our dataset today compared to that of a few decades ago as the measure of 'big-ness', there can be no doubting that archaeology's data is now 'big' (eg Cooper and Green 2016).

As a result, we are facing a considerable and important challenge: the need to synthesise and make sense of this mass of new information. One way of doing so is by creating general spatial models from point data: using the language of Geographical Information Systems (GIS), one might refer to this as moving from 'points' to 'polygons'. The principal advantages of such models are that they condense a mass of individual data into a form which can be readily understood and absorbed by the human mind; that they provide the basis for interpretative rather than descriptive accounts; and that they prompt questions which can be used to drive the design of further data collection.

A small number of examples, drawn from a range of different sources, will suffice to illustrate these general points.

An early attempt at distilling Historic Environment Record (HER) data was that carried out in part of Hertfordshire, where a series of archaeological 'character zones' were defined using point data from the HER, along with information about topography, geology and modern land-use (Hertfordshire County Council unpublished).

Similar approaches have been used in urban contexts. The Lincoln Archaeological Research Agenda (LARA; Jones *et al* 2003) divided the City of Lincoln into a set of period-based zones covering the whole city. For each zone, the study summarised what was known about the archaeology of the zone in that period, characterised its known or suspected archaeological potential, and proposed a series of research questions which could be pursued through further investigations. In Chester, a series of 'archaeological character zones' covering the City of Chester were defined on the basis of information in the Urban Archaeological Database (Cheshire Archaeology 2014).

Probably the most ambitious attempt so far at spatial modelling of archaeological data has been the Oxford-based 'EngLaId' (English Landscape and Identities) project. This has drawn together a very large database (around one million records) covering the period 1500 BC to AD 1086, and makes full use of GIS spatial and statistical analytical techniques, such as Kernel Density Estimates, to produce maps of various kinds (for example, 'heat maps') which present syntheses of different aspects of the data (Green *et al* 2017; EngLaId Team forthcoming).

Archaeological modelling of this kind (one might also call it 'characterisation') raises a number of questions, and it is important to be aware of these.

First, how much data do we have? This is a crucial question. It is possible to make a general model with even quite a small number of data points, but how reliable will it be? Equally, the temptation not to undertake modelling on the grounds that "we don't have enough information yet" should be resisted. Creating models is an important activity: it justifies the effort expended on gathering the data we have already acquired; it enables us to understand the meaning of that data; and it prompts us to ask new questions, in turn stimulating the collection of new data.

A second key question is: how far can we safely extrapolate from the data which we have, from the known to the unknown, from the particular (the data itself) to the general (a model)? This is probably partly a matter of professional judgement and partly one of personal predilection: some people will take a more cautious approach, others a more expansive one. There is no 'right' answer to this question, and the main thing is that anyone who uses a model should understand and respect its limitations. To enable this, it is important that any model should be accompanied by information about the properties and limitations of the raw data from which the model has been generated, and also about how that data has been processed to construct the model. Both factors will influence the nature and reliability of the model.

Closely linked to the previous point is a third question: what 'resolution' does the model have? A model may look very detailed, precise and accurate but it is just that (a model), and may well involve a lot of extrapolation. It is important to be aware that any particular model may be reliable and suitable for particular purposes at one scale, but not at another.

This raises a fourth issue: how do we ensure that the models we create are treated as being just that – models, and as such always in need of testing – rather than coming to be seen as solid fact? This danger is ever-present. So, too, is the related one of models becoming self-fulfilling prophecies. For example, a model which suggests that there is little to be found in a particular area may lead to a lack of further investigation there, which could simply reinforce a possibly erroneous view of the area. Both dangers need to be carefully guarded against.

These are important issues, and sometimes problematical ones. In no way, though, do they call into question the value of modelling. Indeed, given the rapid rate of growth in our archaeological data, modelling (of whatever kind) and the development of modelling techniques are increasingly necessary. In fact, they are essential to the advance of archaeological knowledge, and to the health and development of the discipline.

Finally, as something of an aside, it is worth noting that there is a wider current interest in modelling the overall subsurface character of urban areas, as an aid to planning and development at large. Such an approach is being pioneered in Glasgow, for example (NERC BGS 2018); if this kind of activity gathers pace, then archaeological information and deposit modelling can surely both contribute to, and gain much from, integrated approaches to subsurface modelling.

I would argue, then, that deposit modelling, as exemplified by the papers in this volume, represents a paradigm case of the process of creating general (and predictive) archaeological models from inevitably incomplete data. For that reason, this volume should be of close interest to anyone who has to grapple with the problems of making sense of large volumes of archaeological point data, whether in two dimensions or three.

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SECTION 1

Introduction

1. Deposit modelling: an introduction

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1.1. Introduction

The idea for this collection of papers arose from the editors' experiences of using deposit modelling as a method of archaeological evaluation and as a means of informing mitigation strategies. It had become increasingly apparent to us, as both practitioners and end-users of deposit models, that there was a variable uptake of such methodologies across the archaeological sector in the UK. Part of this variability in applying deposit modelling can be traced back to undergraduate archaeological degree training. In the UK, few programmes deliver introductions to the principles and methods of deposit modelling, while even fewer provide significant training in geoarchaeology. In the recent past, this knowledge gap was addressed by in-depth training in geoarchaeology at Masters level, but this has also declined in the last decade. In our experience, many professional archaeologists are either unaware of deposit modelling or lack the confidence to apply such methodologies, despite their potential to deliver significant knowledge gains.

Therefore, the primary aim of this volume is to bring deposit modelling and geoarchaeology closer to the centre of archaeological field investigation, providing examples of best practice for practitioners, consultants and heritage managers. We hope that this will enhance historic environment evaluation and mitigation strategies and facilitate the creation of cost-effective schemes of investigation for developers. This volume of case studies supports the Historic England Guidance Document *Deposit Modelling for Archaeological Projects* that is currently in preparation by the current editorial team. It is hoped that these two publications will emphasise the value of deposit modelling to the wider body of heritage practitioners and enhance further the dialogue with the non-specialists who constitute the majority of project managers (responsible for designing and executing projects), curatorial archaeologists (responsible for writing project briefs) and the clients who commission archaeological work in advance of development.

To date, deposit models have not been considered a key part of the majority of archaeological investigations, and they often end up as stand-alone grey literature reports or, if part of a site publication, as an appendix; therefore, they are often not widely disseminated. However, largely as a result of the efforts of key practitioners and organisations, many of whom have contributed to this volume, deposit modelling is growing in its application within the historic environment sector. Quantifying the current uptake and impact of such methodologies across the sector is more problematic, since there are relatively few examples published in peer-reviewed journals or monographs.

This edited volume focuses upon British terrestrial environments and comprises a series of case studies aimed at demonstrating how deposit modelling can be used effectively for investigations of archaeological sites and their wider landscapes in a wide variety of geomorphic settings (including estuarine and coastal zones, but excluding offshore areas). The studies consider a range of methodological approaches to deposit modelling over a wide timescale, with assessment of the baseline data used, challenges encountered during execution of the work, the project outputs and the effectiveness of the methodologies that were employed. The individual case studies are structured by reference to a standard template, including summary tables and flow diagrams, which it is hoped will enable readers to compare and contrast more effectively the strategies described for different sites. These case studies are supplemented by two overview chapters, focusing first upon the development of deposit modelling as practiced in archaeology (Chapter 2) and secondly upon the challenges and opportunities currently facing the application of deposit modelling in archaeological projects (Chapter 18).

1.2. What are deposit models and what can they contribute?

In their simplest form, deposit models provide visual representations of the spatial and stratigraphic relationships between sediments, archaeological and palaeoenvironmental remains in areas preserving both vertically and laterally accreting sediment sequences. Such areas may preserve artefacts, ecofacts or structural remains within and beneath sedimentary units that cannot be detected by surface survey or by traditional prospection techniques such as terrestrial geophysical survey. In such sedimentary contexts, deposit modelling provides the most effective strategy for investigating the subsurface stratigraphy and the potential for the preservation of associated palaeoenvironmental and archaeological remains. Not only can a deposit model guide the investigation strategy on an individual site, but, at a larger scale, a similar modelling process can make sense of large datasets and disparate data, illustrate archaeological potential and provide a context for archaeology within the wider landscape.

Information acquired during modelling on the depth of the sediment sequence, the distribution of buried land surfaces and palaeosols, the presence of landforms such as palaeochannels, river terraces or buried dunes provides crucial evidence for the formulation of archaeological evaluation strategies. Data obtained during this work inform the scale and variety of resources that are needed for subsequent phases of mitigation, and, by assisting the development of risk management strategies, have the potential to reduce overall costs and minimise damage to the heritage resource – thus benefiting curators, consultants, archaeological contractors, developers and other stakeholders. Such models also provide platforms for archaeologists to communicate more effectively at site level with civil engineers and other construction professionals who use 3-dimensional information models as a common currency of project development. Since these models are constructed within a digital, highly visual environment, they afford valuable opportunities for heritage specialists to provide their clients with a clearer understanding of the decision-making process underlying proposed evaluation and mitigation strategies.

1.3. Spatial and temporal scope of deposit models

Deposit models are suitable for any environment where sediments have accumulated and there is the possibility of archaeological remains, regardless of post-depositional histories. They have been applied in Britain to a wide variety of geomorphic environments of Pleistocene and Holocene date, as demonstrated in this volume by Bates' overview (Chapter 2) and by the individual case studies.

1.4. At what stage in the archaeological process should deposit models be constructed?

A deposit model should be prepared as soon as possible during programmes of archaeological investigation in order to guide the development of field research or, in the case of work in advance of development, evaluation and mitigation strategies. The commissioning of a geoarchaeologist during the compilation of a desk-based assessment can assist in the capture and interpretation of appropriate datasets and contribute significantly to the understanding of sites and their settings prior to the commencement of fieldwork. If essential geotechnical information is unavailable, it should be commissioned as part of a programme of bespoke ground investigations to be undertaken prior to and/or during early stage archaeological evaluations. However, investigators should ensure that they have exhausted their search for available datasets before commissioning new studies and not rely solely on what the developer can provide in advance. The case studies that are presented in this volume have been selected with the aim of demonstrating the benefits to all parties of this staged approach in a wide range of Pleistocene to Holocene sedimentary environments.

1.5. How are deposit models constructed?

Deposit models are usually constructed by dovetailing archaeological records held in County Historic Environment Records (HERs), museums and other archives with geotechnical data describing the thickness and geometry of sedimentary units, airborne and ground-based remote sensing survey data (often held by quasi-governmental organisations such as the Environment Agency), information derived from academic research (including doctoral theses and the field guides of the Quaternary Research Association [https://www.qra.org.uk/]) and data provided on maps and in online, open-science resources (eg British Geological Survey OpenGeoscience service: http://www.bgs.ac.uk/opengeoscience/).

Geotechnical data can be obtained from borehole and window samples (derived using a variety of augering equipment), natural sediment sections, trial-trench or test-pit sections and plots derived from geophysical surveys. Data may sometimes derive from previous archaeological investigations, and in such cases data collation can be standardised. In the majority of cases, however, deposit models are compiled from pre-existing data sources such as engineering boreholes and test-pits; they will commonly be based, therefore, upon data collected for non-archaeological purposes, at different time periods, and using a wide variety of methods and recording systems. In such cases, the available data need to be assessed carefully by an experienced geoarchaeologist prior to interpretation.

Analyses of surface landform assemblages from airborne remotely sensed imagery of varying sophistication and resolution, including vertical aerial photographs, lidar, and multi-spectral or hyper-spectral data, may provide further important insights into landscape evolution and geological formation processes. The increasing use of terrestrial geophysical techniques opens up further opportunities, although interpretation can prove challenging. Unlike borehole data, geophysical techniques record the sediment stratigraphy by proxy rather than directly (eg by resistivity values expressed in ohms.m). Such readings need to be correlated with the coeval sediment units before subsurface deposit variations can be categorised and modelled, although the continuous nature of geophysical data considerably aids such interpretations. Fundamentally, at least some borehole sampling or sediment logging (eg by gouge coring or by observations of trench sections) should be conducted alongside these geophysical surveys to provide a control on the variation displayed in the data.

1.6. Basic deposit models

Once stratigraphic information has been collected, it can be visualised in a variety of ways, not all of which need employ sophisticated software. For example, at the most basic and traditional level, a deposit model might comprise a hand-drawn section illustrating the 2-dimensional stratigraphy of a site, correlations between the sedimentary units, and key interfaces between discrete borehole logs or recorded sections.

To increase the spatial understanding of any study area, multiple hand-drawn 2-dimensional cross-sections might be constructed to intersect through the same data points (sediment logs); termed 'fence diagrams', these allow the correlation of units within a pseudo 3-dimensional

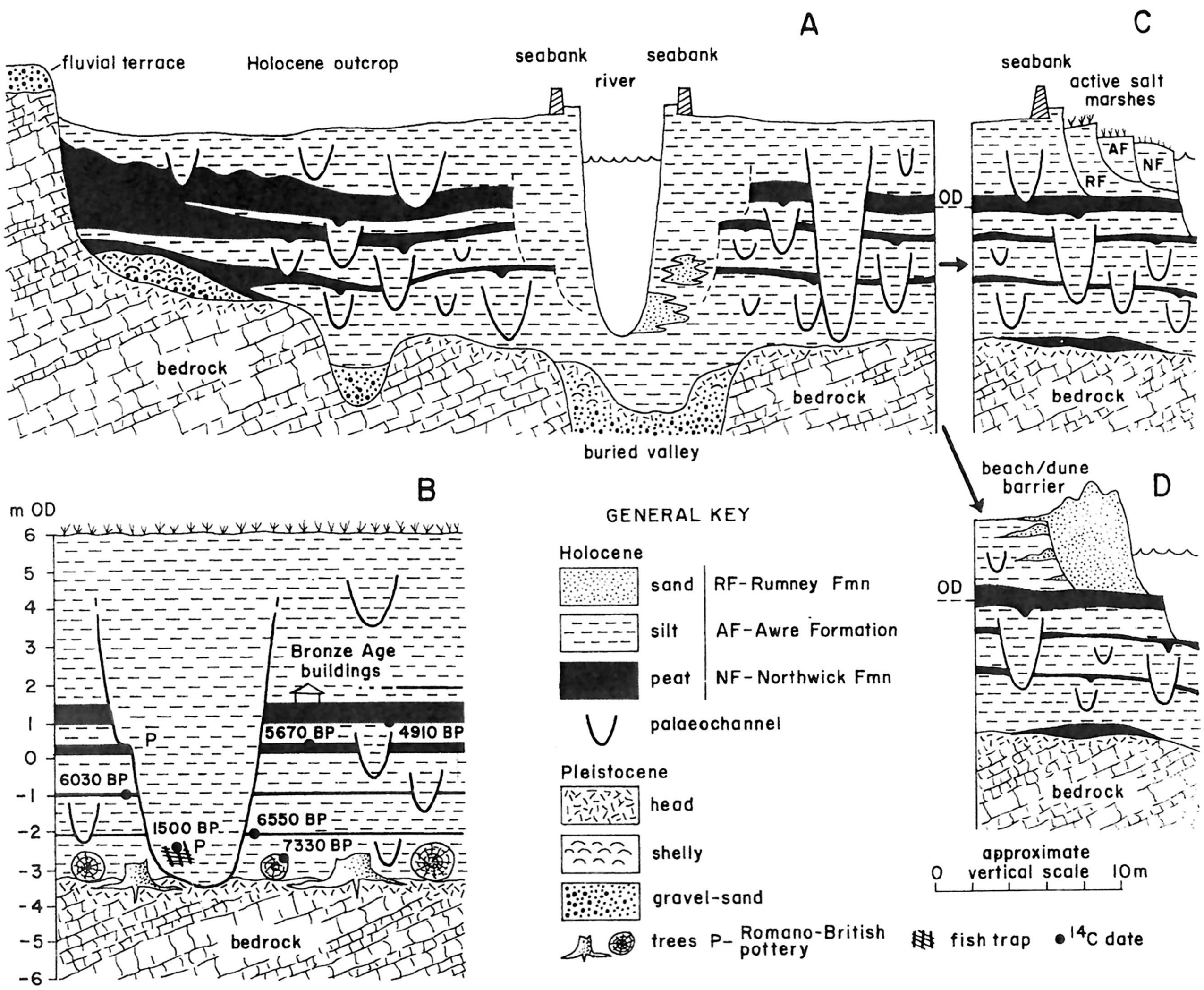

Figure 1.1: Schematic illustration of the later Quaternary sequence of the Severn Estuary levels (reproduced with the kind permission of Professor J. R. L. Allen 2000 and The Severn Estuary Levels Research Committee)

framework, but can be constructed with or without the aid of computers. Furthermore, if a deposit model is being used as a general illustrative aid to heritage management, it can be presented in a schematic way as long as the parameters of its use are clearly defined (Figure 1.1). For the purposes of archaeological mitigation, however, accurate, scaled representations should be considered best practice.

1.7. Advanced deposit models

The growth of computing and associated software during the 1980s provided an opportunity for archaeologists to employ point data for the depiction of stratigraphic surfaces as either contour maps (eg Merriman 1992) or meshed land surfaces (e.g. Brown and Keough 1992; Dinn and Roseff 1992). As personal computing power developed, bespoke geotechnical software developed. Early examples of its potential for studies of deeply stratified sediments and discussions of methodological approaches are provided by Bates and Bates (2000), Bates (2003) and Challis and Howard (2003), in all these cases in the context of alluvial landscapes.

Since the turn of the 21st century, it has become standard practice to use Geographic Information Systems (GIS) to capture and manage archaeological information; as well as commercial products such as ArcGIS (www.arcgis.com), these software packages now include sophisticated, well-supported, open-source platforms such as QGIS (www.qgis.org). These software packages provide opportunities to map unit bounding surfaces (which may themselves represent palaeolandsurfaces) and other units of archaeological interest (such as organic-rich remains with the potential for palaeoenvironmental reconstruction) or to construct isopach maps illustrating unit thickness (Corcoran *et al* 2011; Howard *et al* 2001).

The management of such information within a GIS also provides the opportunity for archaeological assessment and management to move beyond the immediate impacts on site stratigraphy and to consider wider management issues: for example, the relationship of organic-rich remains to local groundwater conditions and the impact of the latter on preservation potential (notably at Nantwich: Historic England 2016; Malim, Chapter 15, this volume). However, whist GIS technology provides an opportunity for spatial mapping of stratigraphic surface interfaces, deposit modelling is not its primary function. GIS modelling thus offers only a pseudo-3-dimensional environment in which to construct deposit models. By contrast, bespoke commercial software packages such as RockWorks (www.rockware.com) provide the most powerful capabilities for stratigraphic visualisation and data management, allowing extrusion of solid layers to produce pseudo-3-dimensional deposit models. However, as with GIS techniques, it is vital to ensure that use of these packages is not assumed to imply more robust models than are justified by the quality of the available data or the experience of the staff employed to use the software.

1.8. Establishing chronological controls

Whilst dividing sediments on a site into discrete stratigraphic units is the first step in the creation of a deposit model, classification of the sediments and determination of their origins provide no chronological control beyond the simple geological law that in an undisturbed natural sequence the oldest sediments are at the base and become younger upwards. Human activity, particularly on urban sites, can impact significantly on sediment deposits, and care is needed in sequence interpretation. Furthermore, this technical guidance is directed towards deposit modelling studies in the relatively stable UK landscape, which does not suffer from the active tectonic processes experienced in many other regions of the world. Caution should therefore be exercised in applying the guidance developed for the UK more widely.

In the first instance, typologically diagnostic archaeological remains interstratified within any sedimentary sequence may provide dating control. However, given the potential for reworking of materials within environments such as the redeposited river gravels of the River Trent (Knight and Howard 2004), absolute dating of the sediments themselves or of associated remains by techniques such as radiocarbon, optically-stimulated luminescence or geomagnetic dating is highly desirable.

1.9. Archiving and dissemination

Despite the proliferation of modelling activities, deposit models are often presented as stand-alone reports and/or as appendices to reports on archaeological investigations, even if specified as an integral part of a tender brief and the resulting Written Scheme of Investigation. Unfortunately, the information provided by these models is rarely fully integrated within the site narratives that are presented in published or grey literature.

Currently, there is no requirement for deposit modellers to archive either their primary or secondary datasets beyond their immediate organisations, though some information may be deposited with local Historic Environment Records and/or the Archaeological Data Service (ADS) as part of the wider package of site archiving. The wider availability of pre-existing datasets and models would provide opportunities to refine and enhance the current knowledge base in the light of new studies. Given that open-access to scientific data is becoming increasingly viewed by national governments and the wider scientific community as best practice, and is now a stipulation of many major funding organisations, it seems likely that such practices will filter down to the archaeological community in due course. Therefore, the need for this community to develop protocols and best practice for data archiving and the sharing of modelling results must be considered a priority task.

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2. 35 years at the trench-face: a personal deposit modelling narrative

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Abstract

Deposit modelling, as practiced within archaeology, has been increasingly used in the UK during the last 35 years to predict the location of buried archaeological remains. This has been particularly useful in developer-funded archaeology, where accurate prediction of buried archaeological remains can significantly save expenditure on unexpected discoveries. This contribution takes a personal view of the uptake in deposit modelling in south-east England over the last 35 years and its impact on developer-funded archaeological works. The contribution begins with a short review of the subject before focusing on south-east England and a case study based on Dover (Kent). The review ends by articulating some important questions that need to be addressed in the next 35 years.

2.1. Introduction

Deposit modelling, as practiced within archaeology, has been increasingly used in the UK during the last 30 years to predict the location of buried archaeological remains (as well as contextualising sites and findspot information). This has been particularly useful in developer-funded archaeology, where accurate prediction of buried archaeological remains can significantly save expenditure on unexpected discoveries. The approaches to deposit modelling vary according to numerous factors, including the background of the practitioners, the terrain being investigated and the nature of development at a particular site. Commonly, however, borehole data is used to construct lithological or stratigraphic models of buried deposits. Increasingly though other forms of subsurface data, including geological geophysics and geotechnical ground test results, are also used to model lithology and/or stratigraphy. In all cases, this information is then coupled with knowledge of the co-occurrence of archaeological remains with particular sediment types in order to predict where artefacts and sites are more or less likely to be preserved.

This contribution takes a personal view of the uptake in deposit modelling in south-east England over the last 35 years and its impact on developer-funded archaeological works. The paper is illustrated by a case study based on Dover in Kent. This contribution does not attempt an exhaustive review, or a step-by-step guide to deposit modelling; rather, it is hoped that some of the key issues and factors that are highlighted will provide insights for the reader and provide a setting for other case studies presented in this volume.

2.2. Deposit modelling: a short review

Deposit modelling is neither a new nor a novel approach to understanding the character or distribution of sediments below the ground surface (Kessler and Mathers 2004). Within the geosciences, what archaeologists call deposit modelling is simply mapping and the creation of stratigraphic models that provide the basis for geological maps, cross-sections and the interpretation of such illustrations. For the geosciences, this process began through recording and interpreting surface exposures or drilling and recording boreholes. Links between observed points of similar character (for example, sediment size, lithology, fossil content) were then made in order to construct local and regional stratigraphic frameworks to interpret earth history. Such practices can be traced back to the early history of geology (Doyle and Bennett 1998).

The primacy of boreholes as a source of information on subsurface lithology is undoubted, and their use can be traced back to the Han Dynasty in China between 202 BC and AD 220 (Loewe 1968). They have been used extensively within the academic community to research earth history and in the geotechnical sector to provide data for construction engineering (Culshaw 2005). However, it was with the development of the new discipline of geology in the 19th century that major strides were made to unravel the stratigraphic framework of earth history. Workers such as Charles Lyell, William Smith, Adam Sedgwick and Roderick Murchison all utilised the ideas of deposit mapping and correlation to create the basis for our understanding of the geology of the United Kingdom (Kessler and Mathers 2004). Today, geological deposit modelling is sophisticated and is used at both landscape (Ford *et al* 2010; Mathers *et al* 2014) and more local (Aldiss *et al* 2012) scales.

Following early developments in geology in the 19th century, it was recognised that the most recent period of earth history, which we now call the Pleistocene, was of particular importance to the study of human origins (O'Connor 2007). Workers such as Joseph Prestwich (1892) used geological sections recorded in different areas of the country in order to understand recent landscape history and construct stratigraphic frameworks. These frameworks were quickly adopted by archaeologists interested in the earliest period of human activity: the Palaeolithic (McNabb 2012; O'Connor 2007). These frameworks became ever more sophisticated in the 20th century, bringing Quaternary geologists and archaeologists ever closer through a shared interest in understanding past earth systems (for example, Zeuner 1946, 1959) For much of the 20th century, these collaborations strove to understand either past chronologies or palaeogeographies by mapping landscape features such as rivers, coastlines and lake edges. In this context, the work in the 1930s of the Fenland Research Committee (Smith 1997; West 2014) highlights an early example of the multidisciplinary use of boreholes in archaeological investigations. Their work resulted in the creation of the now familiar 3-phase sequence of Fenland deposits of East Anglia (West 2014) while Godwin (1940) produced the first synthetic 'deposit model' for the area that linked the stratigraphy of the Fen basin to its archaeological record (Figure 2.1). So close was the link between geoscience and archaeology at this time that, while excavating at Plantation Farm in Cambridgeshire, Grahame Clark requested help from O.T. Jones, the Woodwardian Professor of Geology at Cambridge University, on where to place boreholes in order to complete the stratigraphic sections that he was constructing (Smith 1997).

Until the recent advent of archaeological and geotechnical urban deposit modelling (Moscatelli *et al* 2014; Neal 2014; Price *et al* 2010) deposit modelling was typically the domain of Quaternary geology and prehistoric archaeology. Geologists have commonly applied stratigraphic procedures to the creation of models within which the archaeological record is articulated, either to place sites within their broader and local landscape settings (for example, Bates *et al* 2016; Wenban-Smith *et al* 2013) or to allow sites and/or sequences to be correlated (Bridgland 2006; Bridgland and White 2014, 2015). An example of such a macroscale approach, albeit within an urban context, is the mapping of the

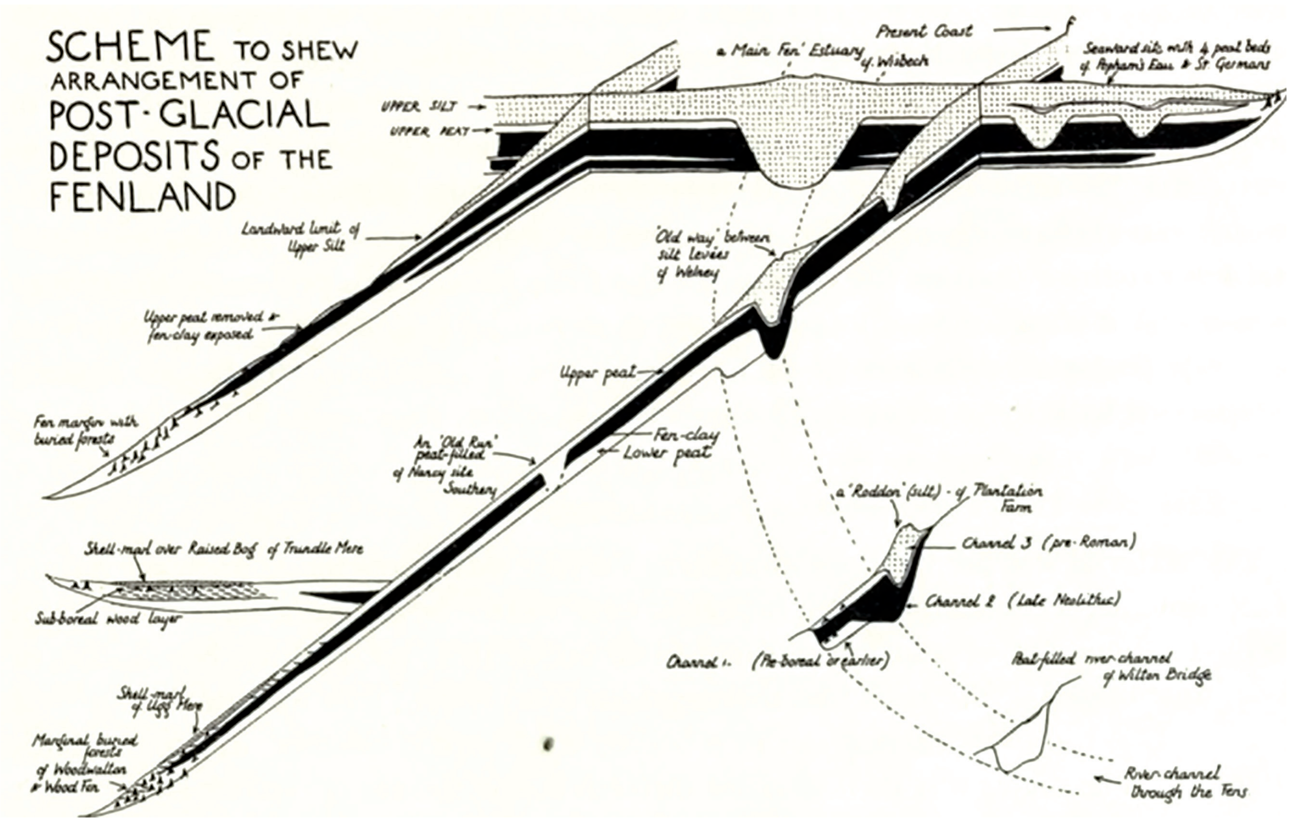

Figure 2.1: Schematic solid section to show type of variation in Fenland deposits and their relationship to features of archaeological significance (from Godwin 1940)

lower Lea Valley undertaken by the Museum of London Archaeology (Corcoran *et al* 2011). More recently, the Aggregates Levy Sustainability Fund (ALSF) provided a number of opportunities for large-scale deposit modelling of Pleistocene sediments in England (Bates and Pope 2016). Beyond the UK, large-scale palaeogeographies spanning both the Pleistocene and Holocene periods have been examined in the alluvial landscapes of continental northern Europe (for example, Berendsen 2007; Berendsen and Stouthamer 2001; Hijma *et al* 2009; Vos 2015; Vos *et al* 2015).

The use of subsurface mapping techniques to explore the extent and nature of known archaeological sites or settlements has also been undertaken using coring and augering methods (Canti and Meddins 1998; Schuldenrein 1991; Stein 1986, 1991), to investigate deposit depth and sediment composition prior to excavation on middens, mounds and tells (Barham and Mellalieu 1994; Reed *et al* 1968; Stein 1986), within rock-shelters (Bailey and Thomas 1987), to monitor physical and chemical ground conditions and preservation of archaeological deposits (Malim *et al* 2015) and to assist in reconstructing off-site palaeoenvironmental records (Apostolopoulos *et al* 2014; Barham 1993, 1999; Barham and Harris 1983, 1985). Coring or use of geotechnical data, such as that described by Culshaw (2005) for geological engineering, has also been deployed to assist in mapping archaeologically significant sedimentary environments beneath urban areas (Barham and Bates 1994a; Bates *et al* 2000; Canti and Meddens 1998; Densem and Doidge 1979; Koster 2016; Neal 2014) as well as 'artifical ground' that would include archaeological units defined by the British Geological Survey (Terrington *et al* 2015).

However, deposit modelling includes a far wider range of techniques other than simply coring, some of which have been utilised and discussed by Barham and Bates (1994a), Bates and Bates (2000), Bates *et al* (2007), Howard *et al* (2008, 2015), Stein (1986, 1991) and Tsokas *et al* (2011). These include other forms of engineering data such as Cone Penetration Tests (Koster 2016), LiDAR data (Howard *et al* 2015) and geological geophysics, particularly landscape-scale Electromagnetic (EM) and Electrical Resistance Tomography (ERT) survey (Bates and Bates 2016; Fischer 2016; Keay *et al* 2009; Missiaen *et al* 2008, 2015; Moscatelli *et al* 2014; Papadopoulos *et al* 2014; Soupios *et al* 2008; Verhegge *et al* 2016; Vouvalidis *et al* 2010).

In summary, four broad areas in which deposit modelling has been applied are:

- The contextualisation of archaeological finds, usually at a landscape-scale. This is typically practiced in association with Palaeolithic archaeology where bodies of sediment such as fluvial terraces and associated deposits can be traced for a considerable spatial extent (Bates *et al 1*997; Bridgland and White 2014, 2015).
- The creation of a topographic setting for an archaeological site and/or the tracing of elements of the site beyond its known boundaries, in either an urban or rural setting (Pint *et al* 2015; Wenban-Smith *et al* 2013).
- The understanding of site structure and internal character. This might be practiced within urban contexts where geotechnical data can provide access to ground that is otherwise difficult to access until the demolition of buildings (De Beer *et al* 2012; Koster 2016; Neal, 2014).
- The creation of models to allow the presence or absence of sites across a landscape to be predicted with more accuracy where sedimentary sequences are deep and conventional archaeological survey techniques such as aerial photography and fieldwalking are of limited value (Bates 1998, 2000, 2003; Bates *et al* 2000; Bates and Stafford 2013; Bates and Whittaker 2004).

The logic underpinning any deposit-modelling project is thus to provide both direct and remote views of the stratigraphy that is buried at depth in the study area (Bates 2000, 2003). Information thus obtained is subsequently utilised to build subsurface ground models, which may be simple or complex depending on the nature of the available data and the familiarity of the practitioner with the area and local geological units.

2.3. Archaeological deposit modelling in south-east England

Today, deposit modelling expertise within both academic institutions and the developer-funded archaeological community is common. This reflects in part the success of a number of geoarchaeologically focused Masters programmes run by UK universities as well as the explosion in archaeological projects in the wake of the introduction of *Planning Policy Guidance Note 16* in November 1990. However, the roots of the development of this branch of geoarchaeology lie within the Institute of Archaeology (IoA) at University College, London (UCL), and its then Director, Professor David Harris.

In the late 1990s, a small team of geoscientists were assembled at the IoA under the guise of the Geoarchaeological Service Facility (GSF). This unit emerged from a project funded by Dover District Council in 1990 to assess the environmental archaeological potential of the deposits in and around a new development in central Dover (Barham and Bates 1990). The unit was a developer-funded service within UCL that offered geological expertise to archaeological projects. It was built on the experience gained by its staff during studies of Quaternary sediment sequences at sites such as Boxgrove in West Sussex (Bates *et al* 1997; Roberts and Parfitt 1999) and of the urban archaeology of London in collaboration with the then Department of Urban Archaeology (DUA) at the Museum of London. Projects undertaken during the

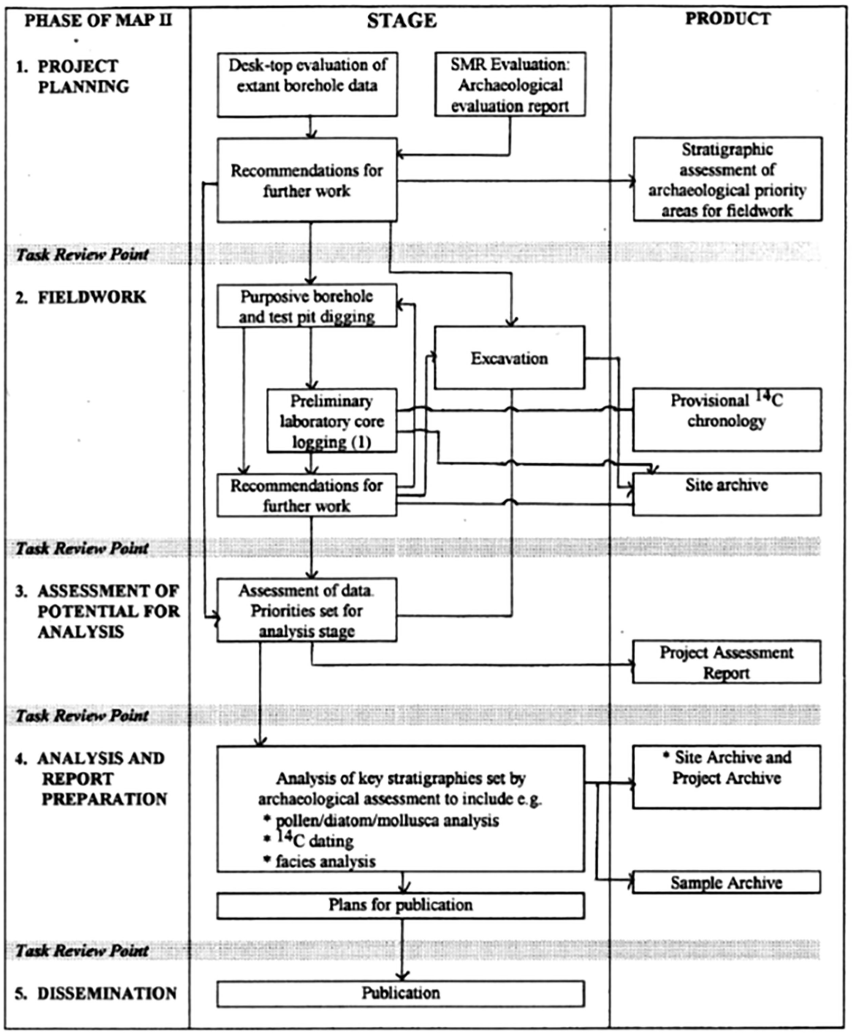

Figure 2.2: A suggested work-cascade for integration of borehole work into the archaeological project design following MAP II structures (from Barham and Bates 1994a)

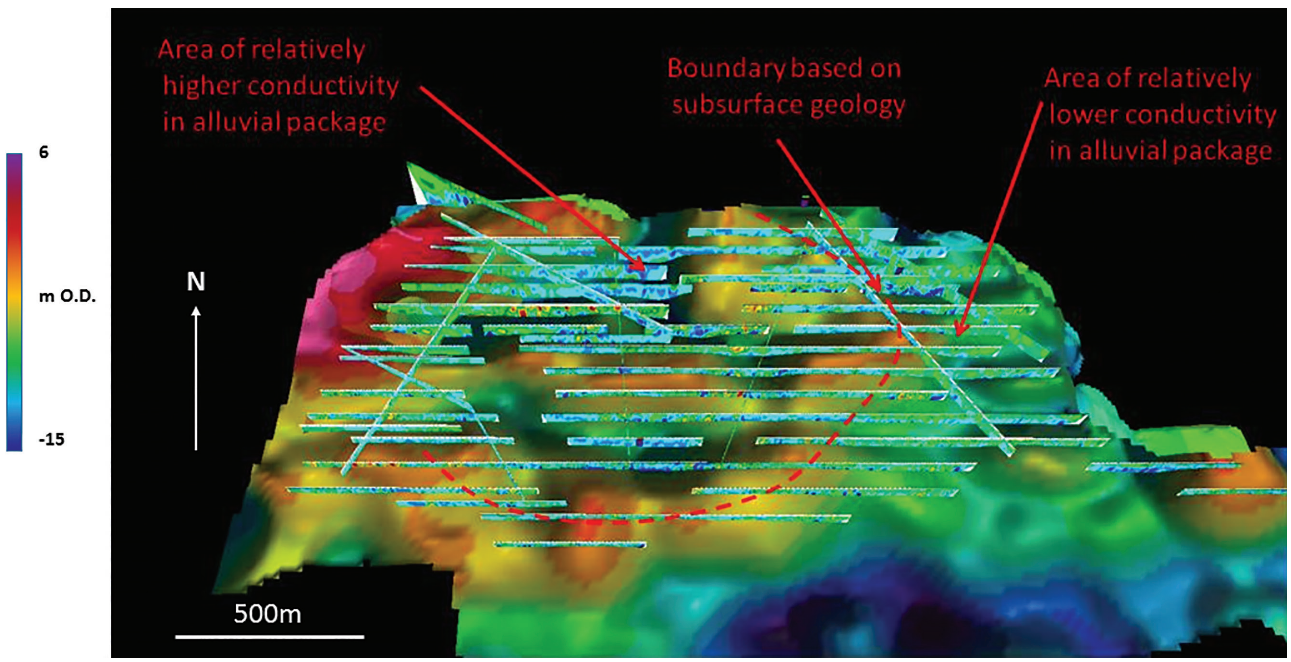

Figure 2.3: Geoelectrical profiles across the London Gateway site (from Bates et al 2012)

lifespan of the GSF (1990–1997) focused on the analysis of geotechnical (primarily borehole) data to create deposit models for areas of deeply stratified alluvium in the valleys of the Thames and other major river systems in south-east England. The GSF was the first group to provide routinely specialist geoarchaeological services to the major field units working in south-east England (for example, to Canterbury Archaeological Trust, Oxford Archaeology, Wessex Archaeology and the Museum of London Archaeological Service). This success quickly resulted in the creation of in-house geoarchaeological support within the major contractor units in the south-east. Guidance documents for the utilisation of boreholes within archaeological projects were produced in-house by the GSF (Barham and Bates 1994a; Figure 2.2). In addition, major infrastructure projects were undertaken (Barham *et al* 1995; Bates and Barham 1993), including the Dover case study described below. Ultimately, these methodologies were applied as part of the package of archaeological projects that was developed in response to the construction of the High Speed 1 rail route through Kent (Bates and Stafford 2013). Towards the end of the lifespan of the GSF, the application of geological geophysics to archaeological problems was being explored; this has since developed a significant role in deposit modelling in southern England (Bates and Bates 2000, 2016; Bates *et al* 2007).

The many organisations undertaking deposit modelling in the south-east of England that were influenced by the GSF have produced multiple deposit models. Amongst the numerous examples of deposit models generated from borehole data, a number stand out for their scale of investigation. These include the Museum of London Archaeology works in the Lea Valley (Corcoran *et al* 2011), Oxford Archaeology's investigations along the line of the A13 (Stafford *et al* 2012) and Wessex Archaeology's mapping of the former Crayford Silts around Crayford (Wessex Archaeology 1999). Projects characterised by smaller-scale borehole investigations are exemplified by works at Belmarsh (Hart *et al* 2015), Canning Town (Nichols *et al* 2013), Silvertown (Crockett *et al* 2002; Wilkinson *et al* 2000) and Barking (Green *et al* 2014). Finally, the integrated use of boreholes with geological geophysics is demonstrated in works undertaken by Oxford Archaeology at the London Gateway port (Bates *et al* 2012; Figure 2.3).

2.4. Dover: a case study

The town of Dover in Kent (Figure 2.4) provides an important case study of not only the application of deposit modelling to the understanding of buried archaeology but also the history of deposit modelling within the Western Heights and Castle Hill areas, with the central part of the town occupying a low-lying position next to the canalised river Dour. The town centre lies at or close to sea

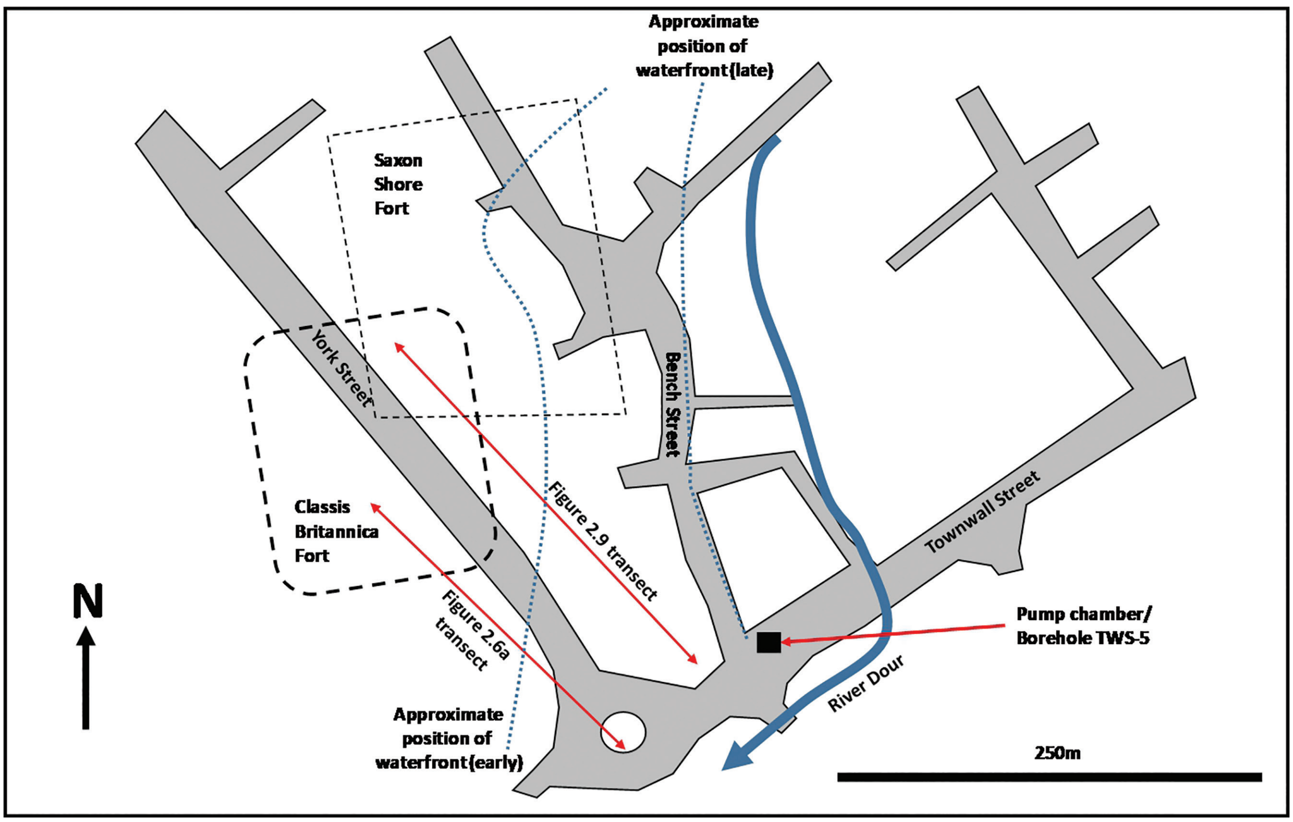

Figure 2.4: Site location plan for Dover

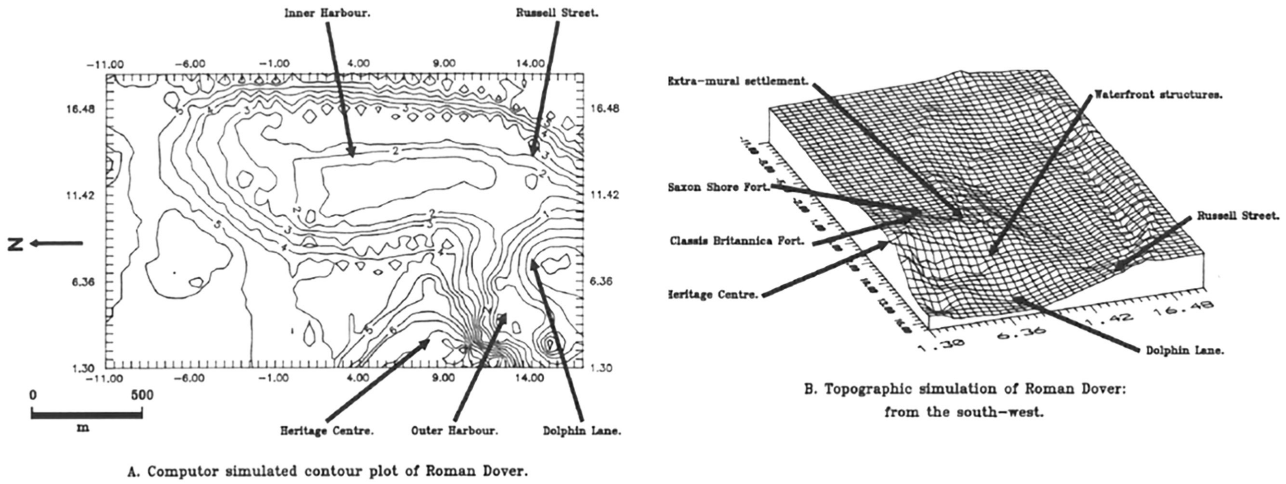

Figure 2.5: Plan and isometric view of the base of the Roman harbour (as modelled in 1990 by Barham and Bates (1990)

level and overlies a thick sequence of marine, freshwater and terrestrial deposits that document the development, flooding and infilling of the estuary and an early harbour of Dover; together, these sequences span at least the last 20,000 years (Barham and Bates 1990; Bates and Barham 1993; Bates *et al* 2008, 2011a). These natural sediments and the presence beneath central Dover of the remains of an older harbour were first noted by Leland:

> *'Dovar is xii miles from Cantorbury and viii miles from Sandwich. There hath bene a haven yn tyme past, and yn token thereof the ground that lyeth up betwixt the hilles is yet in digging found wosye. There hath be found also peces of cabelles and anchores, and Itinerarium Antonini calleth it a haven' John Leland, 1539–1545 (Hearne 1710–1712)'.*

However, it is possible that an older account describing the estuary at Dover exists in the form of Julius Caesar's *Commentaries on the Gallic War*:

> *'He himself reached Britain with the first squadron of ships, about the fourth hour of the day, and there saw the forces of the enemy drawn up in arms on all the hills. The nature of the place was this: the sea was confined by mountains so close to it that a dart*

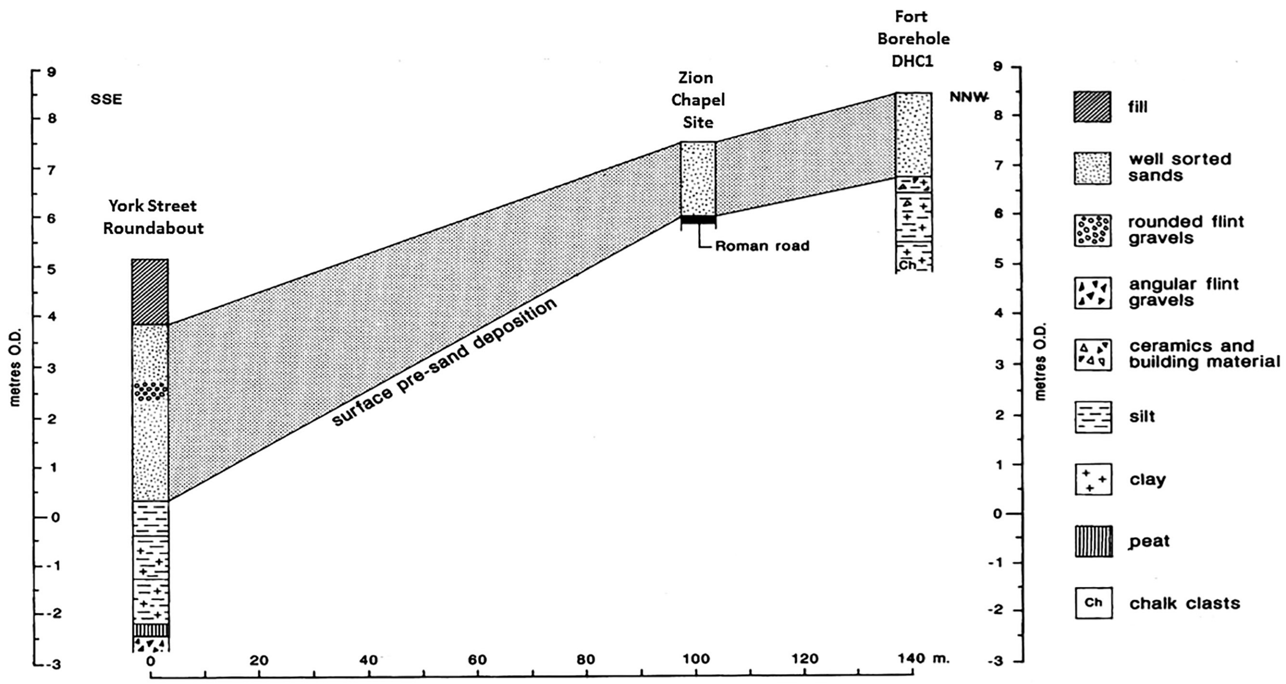

Figure 2.6a: Cross section based on boreholes from the Roman fort to York Street roundabout showing correlation of natural and anthropogenic sediments

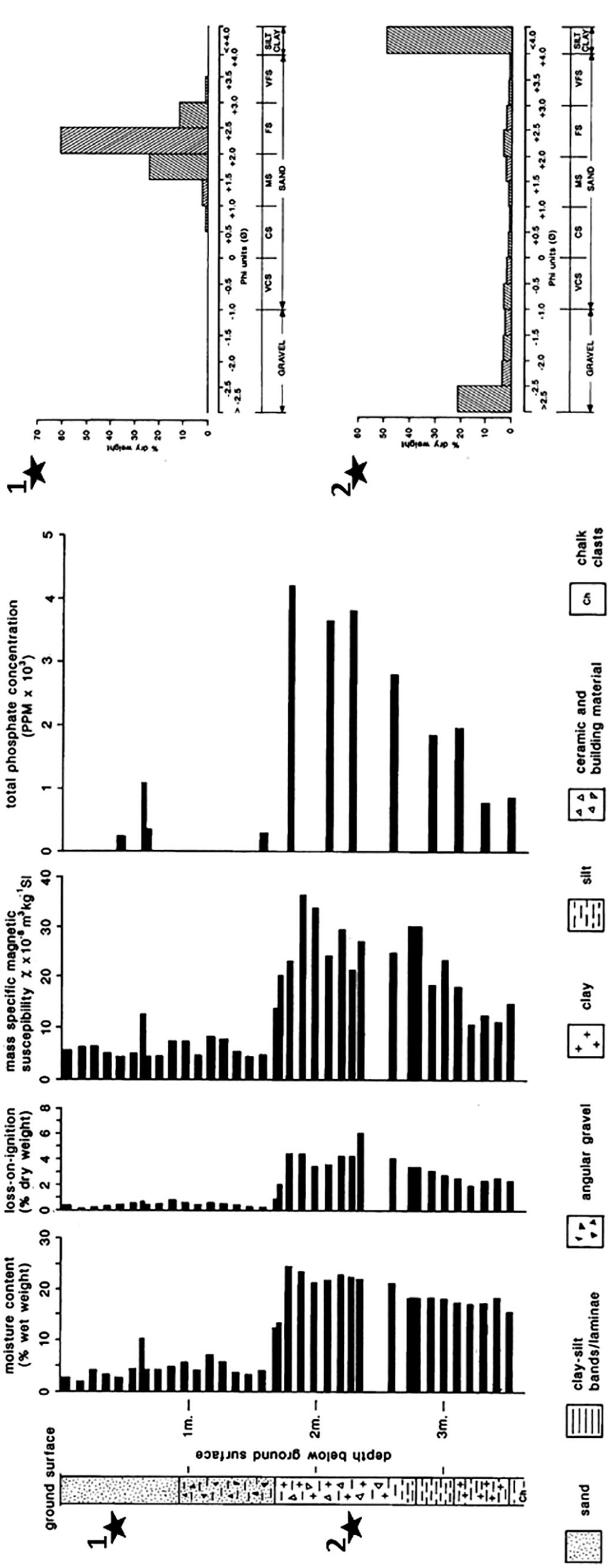

Figure 2.6b: Sedimentological data (including particle size distributions) of sediments from the borehole through wind-blown sands and anthropogenic sediments at the Classis Britannica fort. Both figures modified from Barham and Bates (1994b)

could be thrown from their summit upon the shore' (Caes. Gall. Book 4, Chapter 23, McDevitte and Bohn 1869)'.

Whether or not Caesar is describing the ancient estuary of the lower Dour Valley we know that Dover was home to the Roman forts of the Classis Britannica (Philp 1981) and the later Saxon Shore (Philp 2012) and was the home port for these fleets. The house with the Bacchic Murals (Philp 1989) as well as an older Bronze Age boat (Clark 2004) were also discovered in the town centre area. In all cases, the locations of these structures or finds are, in part, controlled by the position of the original estuary and its history of development.

The Roman harbour (Rahtz 1958; Rigold 1969) has long since been infilled and until recently little was known about it in any detail. Unravelling this history of harbour infilling and growth of the town has a long history in Dover, beginning in the 19th and first half of the 20th century (Bavington-Jones 1907; Elsted 1856; Knocker 1857). These early observations were augmented by opportunistic glimpses prior to the Second World War (Amos and Wheeler 1929) and formal excavations during construction and infrastructure renewal following bomb damage after the war (Rahtz 1958; Threipland 1957; Threipland and Steer 1951). Widespread investigations coincided with larger-scale works associated with urban regeneration during the 1970s and 1980s (Philp 1981, 1989, 2003, 2012) and modifications to the A20 road and town sewers in the early 1990s (Bates and Barham 1993).

Early schematic attempts to contextualise the archaeological remains within the landscape of the Roman harbour were made by Rigold (1969) and this was followed in 1990 by an attempt to draw together all available data into a proto-deposit model for the town centre (Barham and Bates 1990). This work produced the first modelled projected outlines of the shape of the inner and outer Roman harbours (Figure 2.5) based on a combination of borehole data and information extracted from the excavation records. Although crude, the topographic projections appeared to support the ideas of Rigold (1969). This preliminary phase of deposit modelling (or more strictly speaking, surface modelling) was accompanied by borehole investigations undertaken in conjunction with excavations by Oxford Archaeology at the Classis Britannica fort (Wilkinson 1994). These works (Barham and Bates 1994b) attempted, for the first time in Dover, to connect physical elements of the landscape (in this case, windblown sands and the harbour fill sediments) with the archaeological structures of the Classis Britannica fort. This was achieved through the drilling and analysis of purposive boreholes articulated within the deposit model framework then available (Figure 2.6a&b).

The opportunity to test the 1990 model came with the A20 roadworks. Excavation of a deep sewer trench through the town centre (largely along roads that needed to be kept open; Figure 2.7a) precluded the idealized archaeological practice of clearing sites in advance of commencing construction. Thus because of the urbanized character of the area, coupled with the deeply stratified nature of the sediments within the former harbour, conventional approaches to the investigation of the archaeological record required adaptation. The first stage of this project therefore commenced with a desk-top evaluation of extant borehole and trench data. The result of the assessment was

Figure 2.7a: View of sewer trench under excavation. Figure 2.7b: Excavated site. Figure 2.7c: End of trench for recording protected by trench boxes. All photographs by the author

the development of a strategy that combined conventional set-piece excavations (where possible; Figure 2.7b) with a rolling watching brief as excavation of the sewer trench was undertaken (Figure 2.7c). The trench was up to 4m deep in places and utilised drag boxes for shoring, which allowed geoarchaeologists access to the leading edge of the cut for recording and sampling (Figure 2.7c). It was also decided that a series of purposive boreholes (funded by Historic England) were to be drilled in advance of cutting of the trench in order to recover samples through the underlying sediments and to ground truth the geotechnical data. The boreholes would thus inform the archaeological team of the likely presence (and depth) of key stratigraphic units that might be associated with archaeological remains. One outcome of this process was the identification of organic silts and tufa deposits of probable prehistoric age in the base of the valley (Figure 2.8a), some of which were likely to be impacted on by construction activity in the form of the sewer trench and ancillary works.

Tufa and peat were identified from boreholes at the intersection of Bench Street and Townwall Street (Figure 2.4, TWS-5) where a major chamber was being dug for the installation of pump equipment for an underpass from Bench Street to the seafront. Consequently, additional care was taken in monitoring this excavation for these deposits, of presumed late Prehistoric age. The result of this exercise was the discovery of the Dover Bronze Age boat (Clark 2004) (Figure 2.8b&c). Despite succeeding in applying deposit modelling to predicting the location of sediments of archaeological significance (and finding the Bronze Age boat) the next logical step in the geoarchaeological study (analysis of the borehole sequences, construction of an urban archaeological database and the creation of a detailed deposit model for central Dover) did not occur. The reasons for this were complex and centred on problems of funding coupled with the detachment of the analysis of the boat from the main A20 project works (none of which has ever been progressed beyond assessment).

Since the mid 1990s, refinements of subsurface models for Dover have been piecemeal (Figure 2.9). Particular focus was rightly given from an early stage to the sequences associated with the Dover boat (Clark 2004). Keeley *et al* (2004) published an account of the palaeoenvironmental context of the boat but failed to contextualise adequately this find within either its local or regional geographic context. This failure to contextualise such an important find (despite the availability of suitable datasets) has created significant problems since then, particularly with regard to whether or not the craft was a sea-going vessel (Bates 2013). More recently, work on the right (west) bank of the Dour (closest to the Roman

Figure 2.8a: Tufa and peat in base of pump pit at Townwall Street-Bench Street intersection. Figure 2.8b: Wood appearing from the tufa that was the first indication of the presence of the Bronze Age boat in the trench. Figure 2.8c: Bronze Age boat resting within tufa and on peat. All photographs by the author

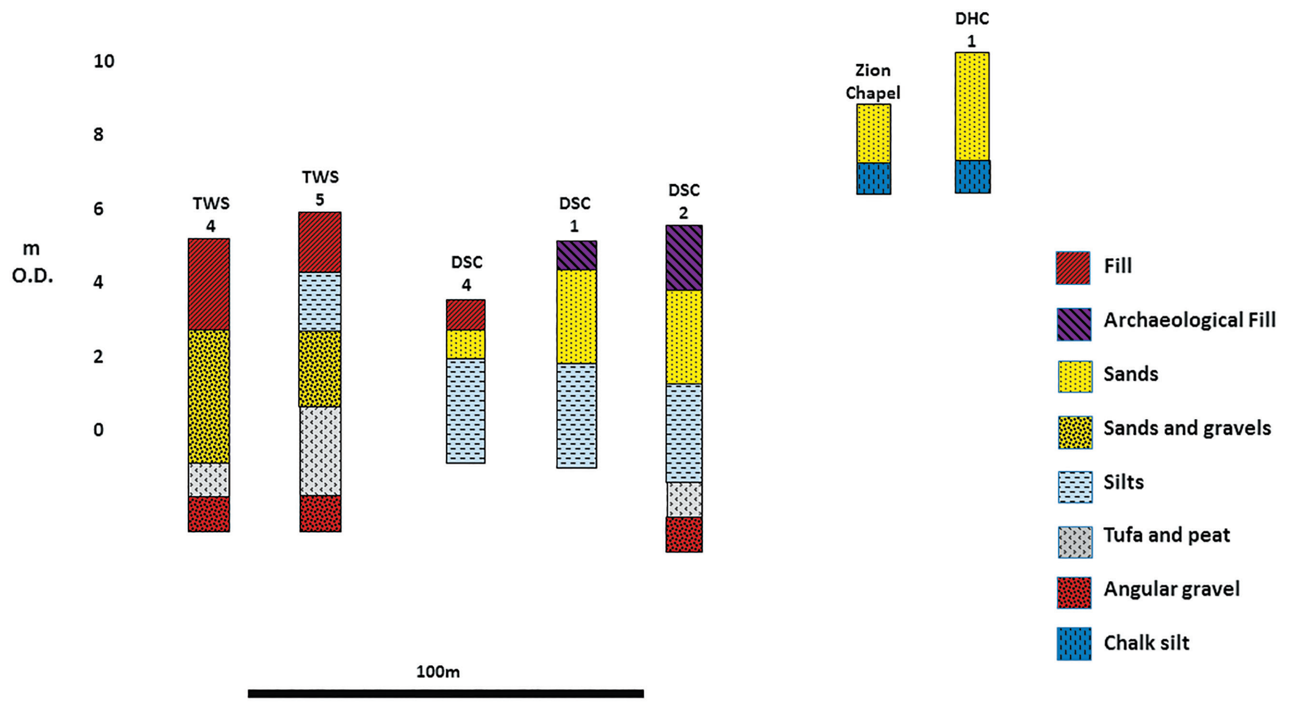

Figure 2.9: Transect constructed from boreholes across town centre area from high ground on west towards the east (from Bates et al 2011a)

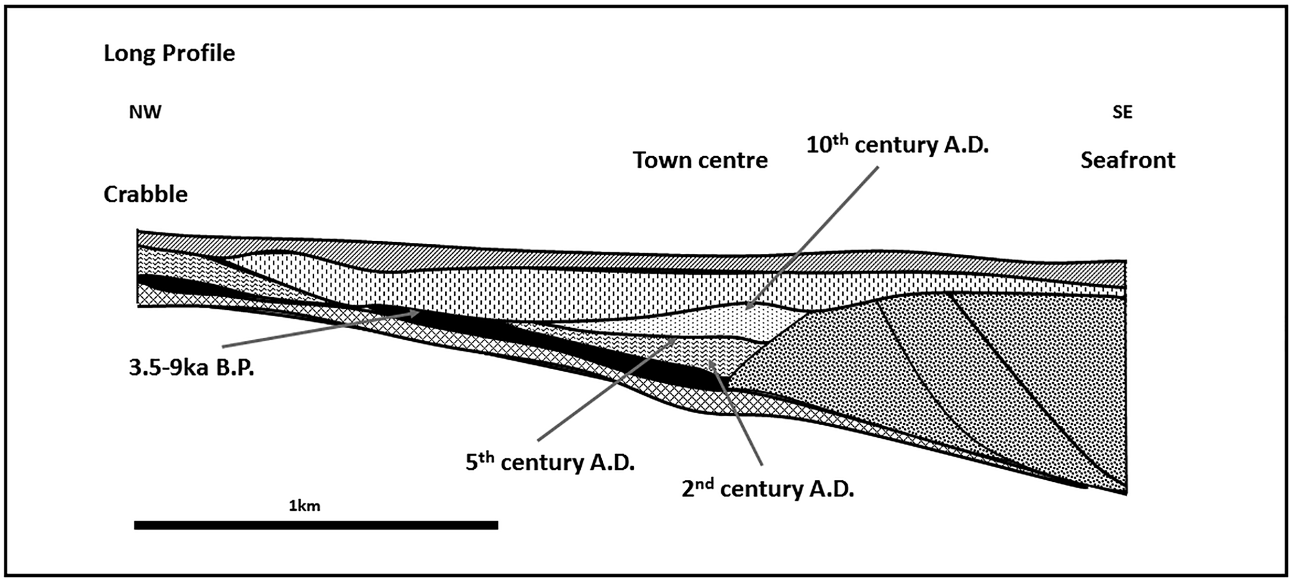

Figure 2.10: Idealised transect along west side of the river Dour for the town centre area constructed from borehole and excavation data (from Bates 2013)

forts) was enabled by the construction of a television screen in Market Square in 2011 (Bates *et al* 2011b). This was linked to a partial re-evaluation of the A20 boreholes and included limited investigation of some samples still extant from the 1990s drilling works. The result was the publication of the first truly integrated deposit model for part of Dover town centre (Bates *et al* 2011a). A simplified long profile down the west side of the Dour Valley is shown in Figure 2.10.

In contrast, the left bank of the River Dour remains rather less well understood. Investigation by Oxford Archaeology of the St James area in 2008 provided an insight into sediments and sequences but little attempt was made to link this to sequences west of the river (Oxford Archaeology 2008) and no assessment of recovered samples was undertaken. At the time of writing in 2016, the Canterbury Archaeological Trust (CAT) are overseeing the archaeological component

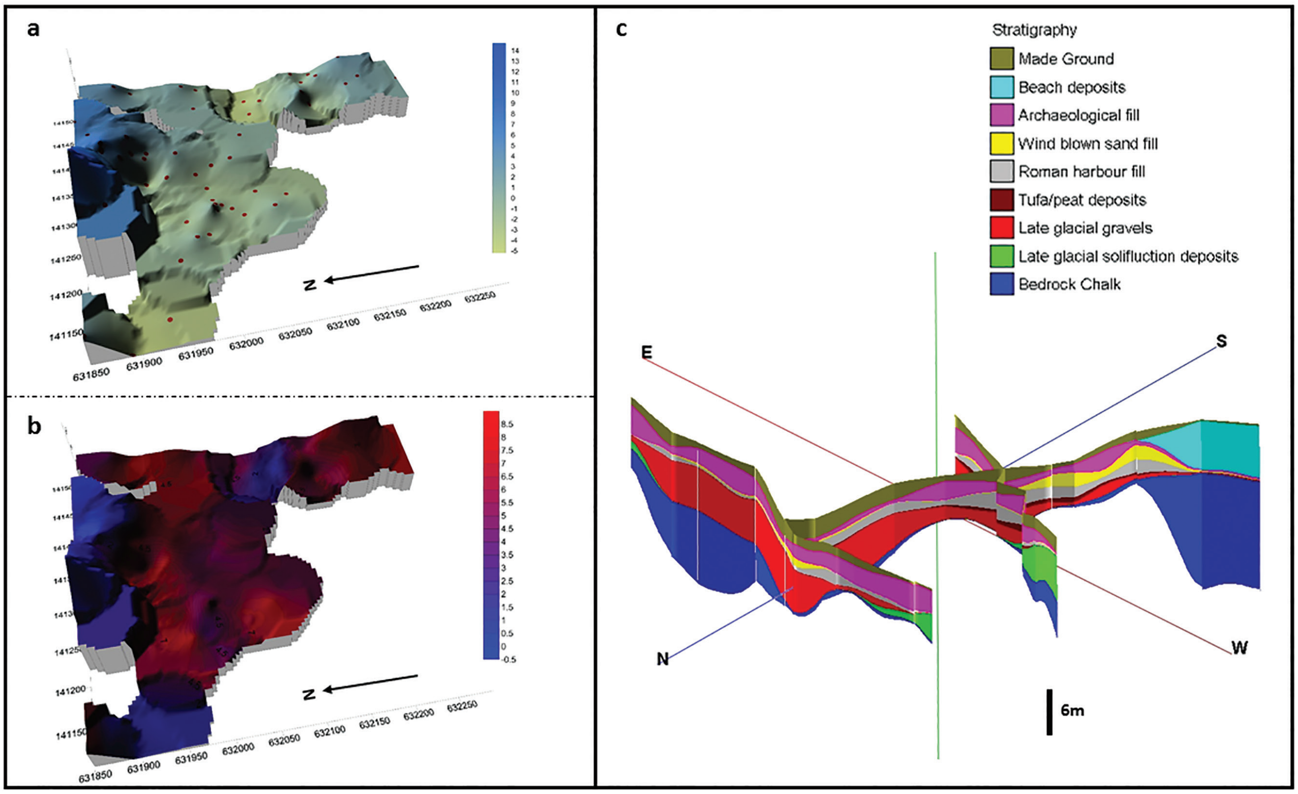

Figure 2.11a: Gravel surface topography and borehole locations (red dots) for town centre area (bounded by York Street, Townwall Street and Russell Street). Figure 2.11b: Thickness of archaeological sediments for the town centre area. Figure 2.11c: Fence diagram of major stratigraphic units for town centre area

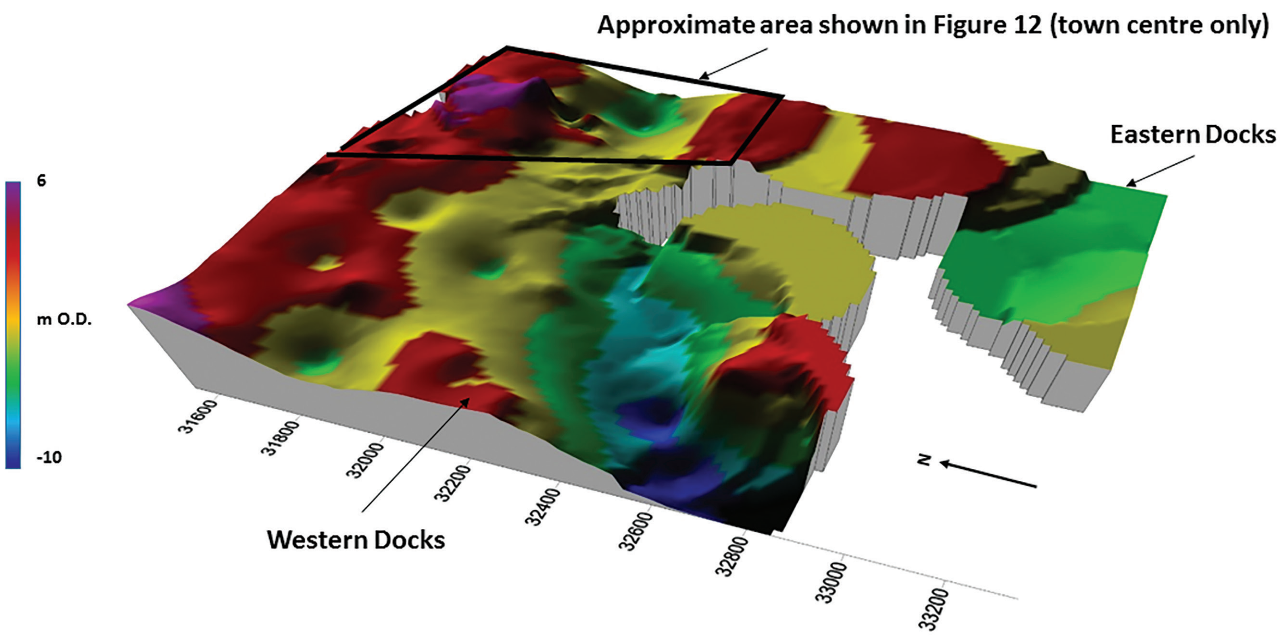

Figure 2.12: Gravel surface topography (base of Holocene) from Western Docks to town centre and Eastern Docks

of a major development project across the St James area; opportunities for ground-truthing of the Oxford Archaeology study as well as historical accounts of the area are on-going, and will utilise a strategy combining open trenches and boreholes. Whilst limited attempts to model the extent and thickness of archaeological deposits across both the east and west sides of the Dour have been made by the author (Figure 2.11), these remain tentative models pending the integration of the 2016 CAT works.

Expansion of the town centre derived model to other parts of the Dour catchment have also been undertaken. In 2004, sediments identified in 1990 and believed to be contemporary with those enclosing the Dover Boat were under threat at Crabble Mill, around 2km upstream of the town centre (Barham and Bates 1990). Excavation and analysis of the sequences were undertaken and published by Bates *et al* (2008). More recently, preparation for re-development of the Western Docks area in 2015 resulted in geotechnical works that provided the basis for an expanded deposit model for the town and docks area (Figure 2.12). These works resulted in ground-truthing of the model through subsequent borehole drilling. The investigation included, for the first time in Dover, the incorporation of bathymetric and seismic profile data into the ground models. In addition to providing detailed information for the urban area, the combination of datasets has been used to consider the landscape setting of the Bronze Age Langdon Bay Hoard, recovered some 500m off-shore (Bates 2013).

2.5. Discussion

Today, nearly 20 years on from the demise of the GSF, the wide range of multi-technique projects that geoarchaeologists undertake in southern England reflects the trajectory established by the GSF in the 1990s. Innovations in computing power, enabling database construction and 3-dimensional modelling of data (Aldiss *et al* 2010; Ford *et al* 2010; Kessler and Mathers 2004; Mathers *et al* 2014), allied with digital acquisition of geophysical data, has allowed complex models to be generated of the subsurface in greater detail than before (see for example Bates *et al* 2012). An increased familiarity of curatorial staff with the concept if not the practice of deposit modelling has resulted in a widespread adoption of this approach.

The future of deposit modelling appears rosy, but we should perhaps be cautious of the volume and detail in the data that is currently available to us. How often are we tempted, when under time and cost pressures, to 'input the data' to the software and 'press the button' to obtain an answer without adequately thinking through the data? How familiar are we with the contexts from which our data is derived? Have we adequately created a forward model, either mentally or physically, before we go into the field to collect data (Bates and Bates 2016)? How easy is it for others to understand our models and, more importantly, the limitations of the models? We rarely, if ever, articulate problems with our models. Those whose projects are tied to developer-funding are often discouraged from being overly critical of the findings of a project when it has been made possible through such funding streams; we cannot be seen to have used the money unwisely! These are all questions and issues that need to be addressed and in some cases require an answer.

Acknowledgments

Through 35 years of deposit modelling the list of people to whom I am grateful is seemingly endless. However, a number of people have played a significant role in helping with the development of approaches to this subject. Firstly I would like to thank Anthony Barham who ran the GSF in the 1990s and David Harris who employed me in the GSF. Keith Parfitt, Paul Bennett and Barry Corke of the Canterbury Archaeological Trust – none of this would have happened without your input and support. I would like to thank my brother Richard Bates, who has been the brain behind the geological geophysics I have used in many projects, John Whittaker, who has tirelessly processed samples for me over the years, and the University in Lampeter, through which I have conducted many geoarchaeological projects since 1997. Finally, I would like to thank Francis Wenban-Smith, Liz Stafford, Chris Pine, staff at Oxford Archaeology and Archaeology South-East, and all others all who have been involved with investigations.

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SECTION 2

Modelling isolated or sparse records left by early human communities

3. Brooksby Quarry, Leicestershire: a deposit model of the Pleistocene sediments of the ancestral 'Bytham River' system

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Abstract

Proposals for a new quarry development within Pleistocene sediments of the Bytham River system, at Brooksby, Leicestershire, during the late 1990s, provided an opportunity to investigate the potential of a palaeovalley known to be rich in Lower Palaeolithic artefacts and early interglacial/interstadial sediments. During the Anglian glaciation (Marine Isotope Stage 12), the Bytham River system was completely destroyed and buried beneath ice, which deposited a significant thickness of ice-contact sediments (tills) above fluvial sediments with potential for the preservation of important archaeological and palaeoenvironmental remains. Following retreat of the Anglian icesheet, a new regional drainage network was established. This was dominated in the Brooksby area by the Rearsby Brook, which incised through the glacial sediments and created an undulating landscape bearing no resemblance to the former drainage alignment.

In order to understand where archaeologically and palaeoenvironmentally significant sediments might be preserved within the Bytham River system, borehole logs supplied by the developer were reviewed and used to construct a 3-dimensional model of the sedimentary architecture in ArcGIS and to identify the major lithostratigraphic units. The model sought to identify major landform features such as palaeochannels and scour hollows, which might contain organic-rich sediments, and channel margin environments which are known to have been particularly favoured by early hunter-gatherer communities.

The modelling identified a major depression trending north-west to south-east through the proposed quarry area, which was deemed to have high geoarchaeological potential. The identification of Lower Pleistocene organic sediments in a number of borehole logs led to a programme of further borehole drilling during the evaluation stage to recover samples for palaeoenvironmental assessment. Since permission to quarry was granted in 2002, the initial borehole model has been further refined, particularly in the area of the bedrock depression where further investigations have included the use of sonic drilling and geophysical survey.

3.1. Introduction

The Bytham River system was the major drainage artery of Midland and Eastern Britain during the Lower Palaeolithic (Figure 3.1), before it was destroyed by the Anglian glaciation (Marine Isotope Stage [MIS] 12) and buried beneath ice-contact sediments (tills) around 450,000 years ago (Rose 2009). Several sites along this palaeovalley, both in East Anglia and the English Midlands, have yielded significant lithic evidence from the fluvial sediments, demonstrating its importance as a migration corridor for early hominins (Ashton 1992; Graf 2002; Keen *et al* 2006; Lang and Keen 2005). At Brooksby, the Brooksby Sand and Gravel represents the lowest lithostratigraphic deposit, immediately overlying the rockhead and includes organic horizons with temperate interstadial or interglacial affinities (Coope 2006; Rice 1991). The temperate deposits are overlain by the main cold stage (MIS 12) sediment body of sand and gravel (Thurmaston Member) and sand (Brandon Member); in turn, these sediments are blanketed by Anglian glacial tills (Figure 3.2).

In advance of a planning application for a new

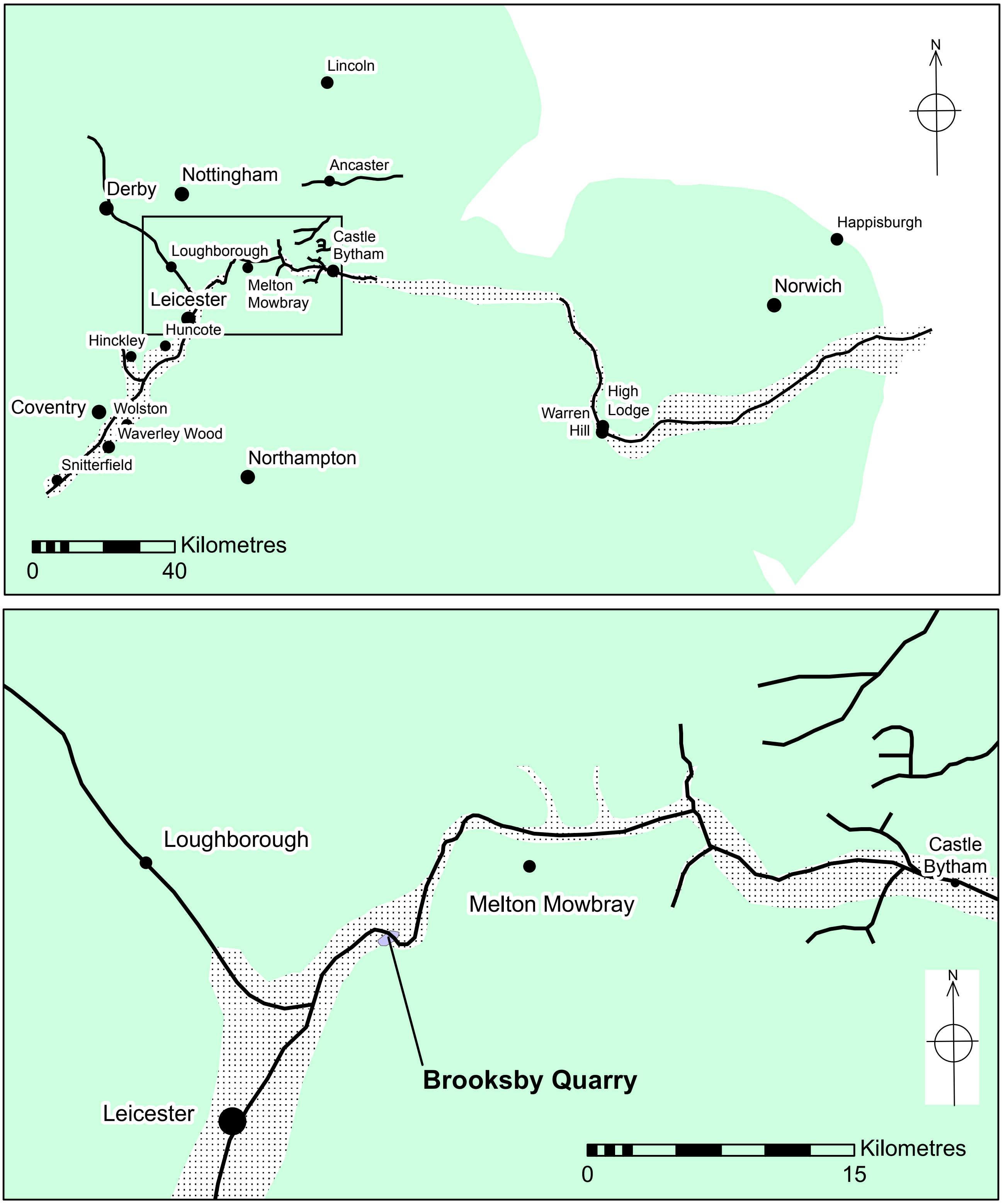


Figure 3.1: Location of Brooksby quarry within the Bytham River system of midland Britain. Important assemblages of Palaeolithic artefacts have been found at Waverely Wood, Warren Hill, High Lodge and Happisburgh and demonstrate the importance of this ancestral river system. The mapped extent of the system is shown by a solid black line. The break in the line within the Fen Basin reflects erosion of this feature by glacial ice, thereby destroying evidence of the river valley in that region

Comparative data table for this deposit model	
Deposit model location	Brooksby, UK (NGR: 67264 15272)
Depositional environment	Buried Pleistocene sediments of the Bytham River system
Size of deposit model	Development area of approximately 170 Ha
Data collection strategies	Review of existing geotechnical data supplied by the client and commission of additional boreholes to sample for Middle Pleistocene sediments with palaeoenvironmental potential
Position in the archaeological process	Review of existing data commenced at evaluation stage
Reason for deposit model construction	To understand the 3-dimensional sedimentary stratigraphy in order to identify areas of high potential for the preservation of archaeologically and palaleoenvironmentally significant remains and to guide targeted geoprospection within a large quarry landscape
Archaeological question	Identify areas of high palaeoenvironmental and archaeological potential to provide the best chance of recovering Lower and Middle Palaeolithic archaeology and proxy environmental records
Software and modelling process	The sediment description data was sorted in Excel, with bounding surfaces and thicknesses of key lithostratigraphic units modelled in ArcGIS
Outputs from the deposit model	A series of bounding surfaces and unit thicknesses related to key lithostratigraphic units were modelled to provide a graphical representation of palaeolandsurfaces

sand and gravel quarry at Brooksby during the late 1990s, a comprehensive archaeological evaluation was commissioned that specifically included a review of published geoarchaeological literature relating to the Pleistocene archive and analysis of pre-existing borehole records provided by the developer (Lafarge Redland Aggregates Ltd). The literature review was undertaken by one of the authors (AJH) on behalf of Trent & Peak Archaeology (TPA) and was incorporated into the evaluation report (Challis and Howard 1999), which considered the wider archaeological and environmental record of the development area. A deposit model (Figure 3.3) was constructed from this borehole data in ArcGIS by another of the authors (KC). Further borehole drilling was undertaken by the original geoarchaeological project team (AJH and KC) but its primary aim was to recover Middle Pleistocene organic samples for environmental assessment.

3.2. Objectives

Whilst the broad regional sequence of lithostratigraphic units, their age and depositional palaeoenvironments were well-established prior to this planning application (Rice 1991; Rose 1987), the development of a coherent strategy for Palaeolithic geoprospection within the proposed development area, particularly associated with future watching briefs, was not well-developed. Therefore, the borehole modelling was underpinned by two key objectives:

- The refinement of local lithostratigraphic knowledge and the identification of any landforms where cultural archaeology might be expected to be preferentially preserved, such as along the margins of major river channels or upon gravel islands.
- The identification of areas where the Brooksby Sand and Gravel, which includes organic remains with temperate affinities, might be preferentially preserved, such as within palaeochannels or bedrock hollows (scours).

As well as informing the research design for the Brooksby area, the development of this large-scale geoarchaeological model in the late 1990s was one of the earliest examples focused on Pleistocene cultural and environmental remains exposed during a large, commercial quarry development; it therefore had considerable generic value at the time of its construction.

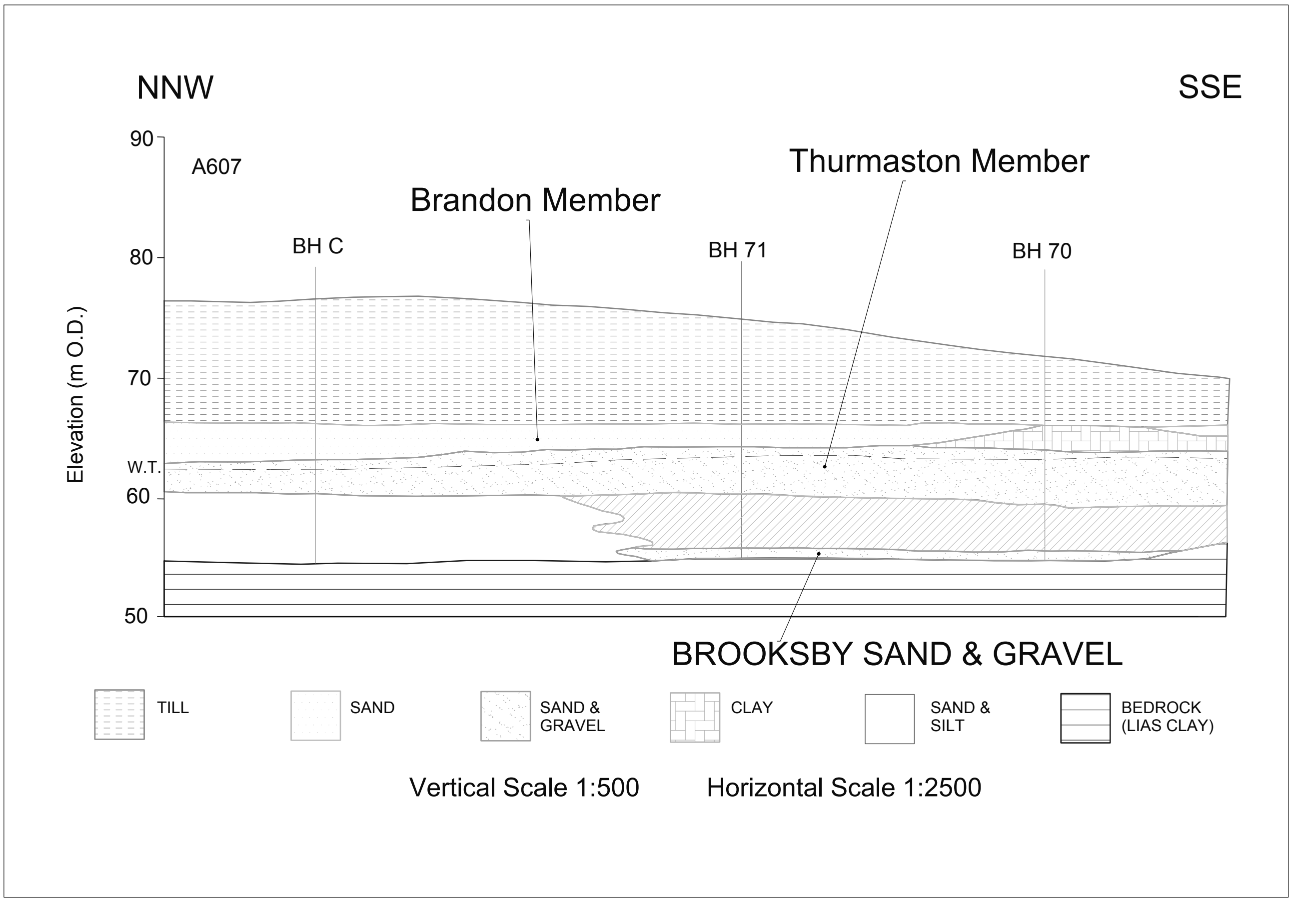


Figure 3.2: Idealised cross-section through the Quaternary sediments in the region of Brooksby quarry illustrating stratigraphic relationships

3.3. Methodology

When investigating archaeological remains within Holocene sedimentary sequences, archaeologists usually take responsibility for describing and interpreting the relatively thin, spatially discrete deposits, which are subdivided on the basis of contexts. In contrast, Pleistocene sedimentary sequences are often much thicker and laterally more extensive (for example, a dissected river terrace of Lower-Middle Palaeolithic age traceable along the entire length of a river valley such as the Thames [Bridgland 1994] or Trent [Bridgland *et al* 2014]). Because of the complexity of these disparate Pleistocene sedimentary records, Palaeolithic archaeologists traditionally work alongside Quaternary geologists who divide and describe deposits on the basis of mappable units (in order of increasing scale, the most commonly used units are 'Bed', 'Member' and 'Formation'). Therefore, unless dealing with discrete occupation surfaces, geoprospection of Pleistocene archives is usually undertaken at a macro- or mesoscale (see Bates and Pope 2015).

At Brooksby, the methodological approach to geoarchaeological analysis was divided into two parts. The first part comprised a review of published geoarchaeological literature relating to the Bytham River system, whilst the second reviewed pre-existing borehole records held by the client (Lafarge Redland Aggregates Ltd). The published literature review relating to the Bytham was targeted on a number of key authors (for example, Professor Jim Rose, formerly Royal Holloway, University of London; Professor Simon G. Lewis, Queen Mary, University of London) and scholarly journals (for example, *Journal of Quaternary Science*, *Proceedings of the Geologists' Association, Quaternary Science Reviews*). A further good source of information was provided by the Field Guides of the Quaternary Research Association (www.qra.org.uk). The aim of the literature review was to establish the broad stratigraphy, chronology and character of the deposits (ie faunal, floral and archaeological content, and depositional environments) as a prerequisite to borehole modelling. Such a stage is considered essential to any modelling study.

Lafarge Redland supplied 94 commercially sensitive borehole records for the site drilled by their own geotechnical team (86 auger holes and 8 cable percussion boreholes). It was noted in personal correspondence preserved with these records that a number of other companies had drilled the area previously (including Ready Mixed Concrete, Tarmac, Tilcon, Pioneer, Ennemix, BFI, Bardon and Greenham), but unfortunately these records remained confidential and were unavailable for review. As well as individual site logs, LaFarge Redland geologists had used the geotechnical information to construct a number of cross-sections across the area. These were supplemented by hand-drawn cross-sections constructed by the project geoarchaeologist (AJH). Stratigraphic interpretations were guided by descriptions provided in the geoarchaeological literature. The commercial boreholes were well-spaced and fairly evenly distributed across the development area, allowing the 3-dimensional stratigraphy to be modelled with confidence using ArcGIS. The surface altitudes (AOD) of all boreholes were recorded, allowing the thicknesses of key lithostratigraphic units to be calculated and recorded in an EXCEL spreadsheet; this provided the primary dataset imported into ArcGIS.

In addition to the borehole logs supplied by Lafarge Redland, 11 additional boreholes were drilled under the supervision of the geoarchaeological team with the principal aim of recovering Middle Pleistocene organic remains for palaeoenvironmental analysis. Drilling for this phase of the project was undertaken by Blue Diamond Drilling Ltd (formerly of Barnstone, Nottinghamshire) and used a flight auger with a maximum drill penetration of 21.5m. Where organic materials were recorded, a second hole was drilled adjacent to the first and sampling was undertaken using U100 aluminium tubes. The Lafarge Redland records illustrate that the sands and gravels beneath the glacial sediments varied from 2.3m-11.6m in thickness, reflecting the undulating nature of the underlying bedrock (Mercia Mudstone or Lias Clays depending on location across the site).

3.4. Interpretation

During the harshest parts of glacial cycles, it is likely that hominins vacated Britain for warmer climatic refugia,

Table 3.1: Summary characteristics of the main lithostratigraphic units at Brooksby quarry

Unit	Environment setting	Potential for the recovery of *in situ* Palaeolithic Archaeology	Potential for the recovery of palaeoenvironmental remains
Till	Deposition directly by ice during glacial cycle	Low: any lithic artefacts are likely to be re-deposited from older deposits	Low: however, the collapse of ground ice depressions and subsequent infilling with organic sediments during periods of climatic amelioration could result in significant localised sequences
Sand (Brandon Member)	Deposition by meltwater-enhanced discharge during cooling late in an interglacial-glacial cycle	Low: any lithic artefacts recovered are likely to be re-deposited either from older terrace or floodplain deposits	Low, although thin scour and slough channel fills may be recorded, as well as eroded organic clasts
Sand and Gravel (Thurmaston Member)	Deposition by fluvial discharge during cooling late in an interglacial-glacial cycle	Low to medium: Any lithic artefacts recovered are possibly re-deposited either from older terrace or floodplain deposits although the material assemblage collected from this unit to date can be classified as 'sharp to rolled' and does not exhibit significant reworking and is probably not far-travelled.	Low, although thin scour and slough channel fills may be recorded, as well as eroded organic clasts
Brooksby Sand and Gravel	Deposition by river during interstadial or interglacial cycle	Medium to high. Lithic artefacts may be recorded on occupation surfaces	Medium to high: organic remains preserved within former river channels and in backswamp floodplain environments. There is also the potential for large faunal remains to be recovered
Bedrock	Not applicable	Not applicable	Not applicable

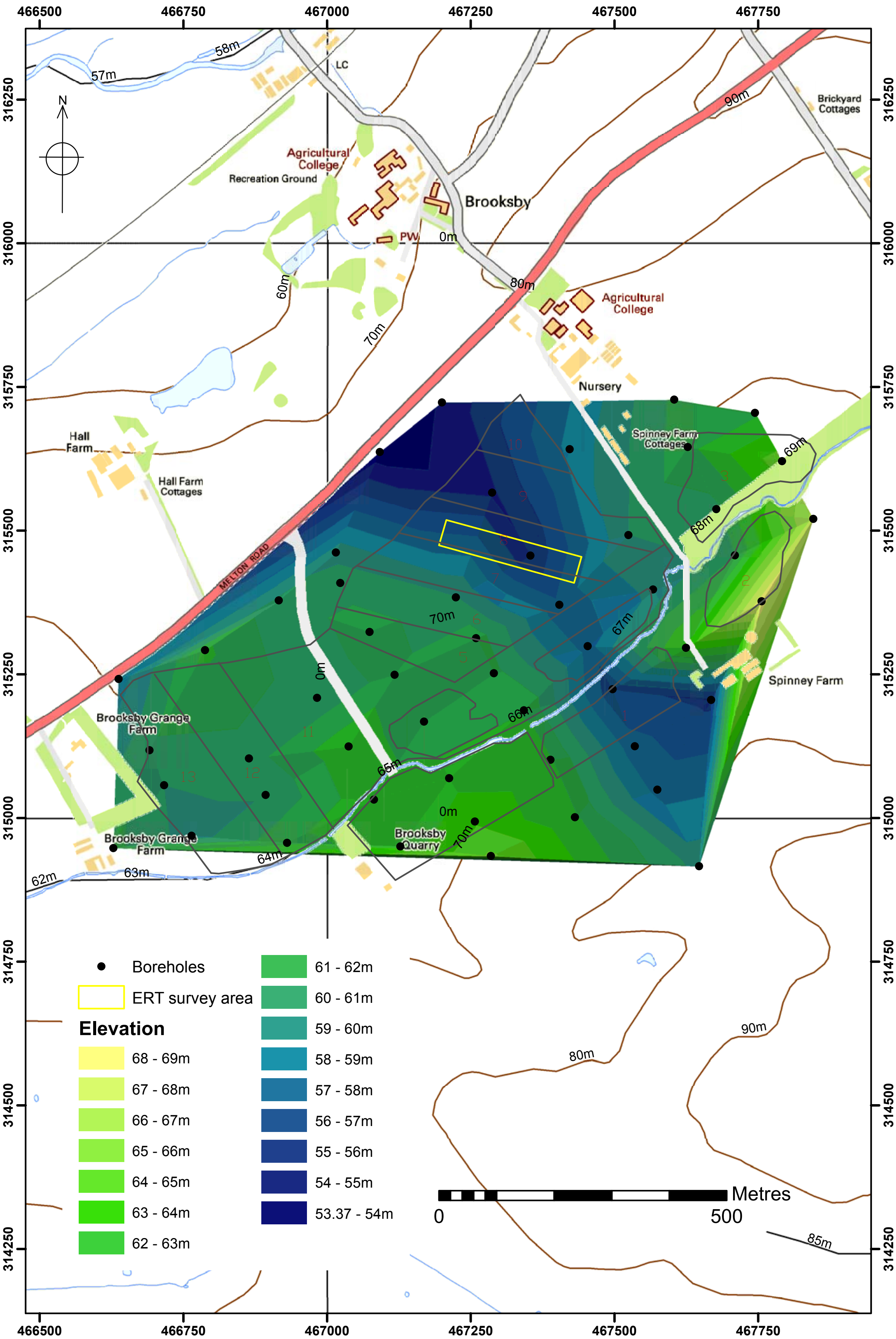


Figure 3.3: Initial rockhead model produced for Brooksby quarry. Company borehole records are shown as black dots whilst the area investigated further and illustrated in Figures 3.5 and 3.6 is demarcated by the yellow rectangle. Contains OS data © Crown Copyright [and database right] 2018.

returning during the ameliorating phases of glacial cycles and during interglacial periods (although evidence of human occupation in Britain is currently lacking for the penultimate interglacial, the Ipswichian; see Ashton and Lewis 2002). During interglacials, the decay of abundant floral and faunal remains resulted in the accumulation of significant accumulations of organic sediment.

The borehole model developed for Brooksby quarry illustrated four key lithostratigraphic units of varied archaeological potential overlying bedrock (Table 3.1).

Modelling of the upper and lower bounding surfaces of key lithostratigraphic units, effectively representing palaeolandsurfaces, identified a major depression in the bedrock, trending north-west to south-east across the site. Based on the site stratigraphy, it was hypothesized that sediments immediately above the bedrock infilling this depression should belong to the Brooksby Sand and Gravel and hence would have the highest potential for the recovery of *in situ* cultural remains (primarily lithic artefacts) and as well as organic sediments with palaeoenvironmental potential. Given the large size of the development area, the longevity of future quarrying and hence the need for several decades of archaeological monitoring, the identification of key areas for geoprospection was essential to target watching brief and other resources. The results of the modelling were fully integrated within the evaluation report as pseudo 3-dimensional surfaces.

3.5. Refining the deposit model: further field investigations

After securing planning permission and the opening of Brooksby quarry, archaeological mitigation of the site was taken over by the University of Leicester Archaeological Services (ULAS). The borehole model developed by TPA has provided the foundations for further investigations and has informed the watching brief and limited excavation strategy (Beamish 2011, Beamish and Jarvis 2015). Since quarrying commenced in 2006, and, as of January 2017,

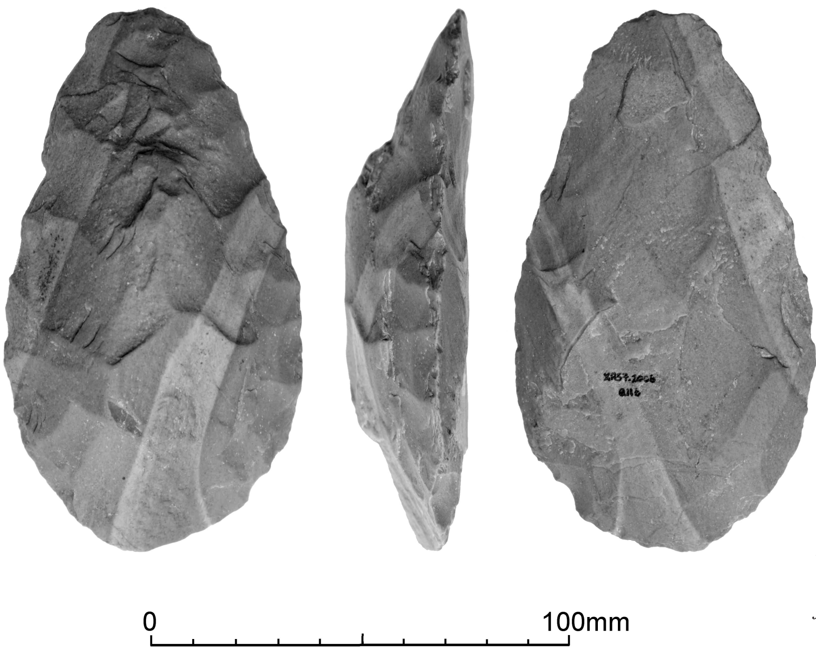
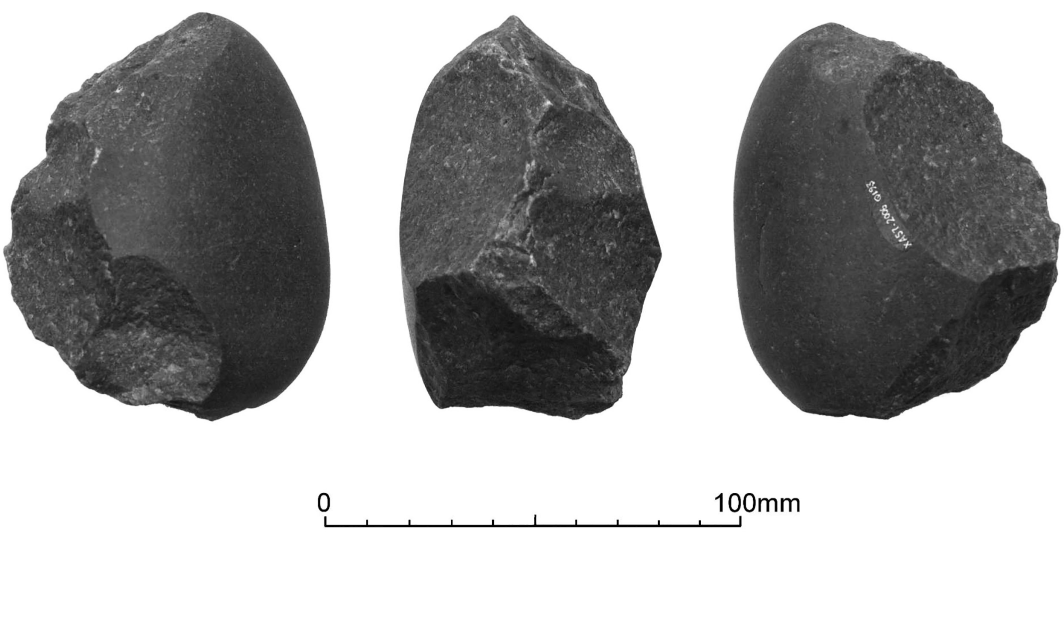


Figure 3.4: Examples of rhyolite (upper plate) and quartzite (lower plate) artefacts recovered from Brooksby quarry during the watching brief



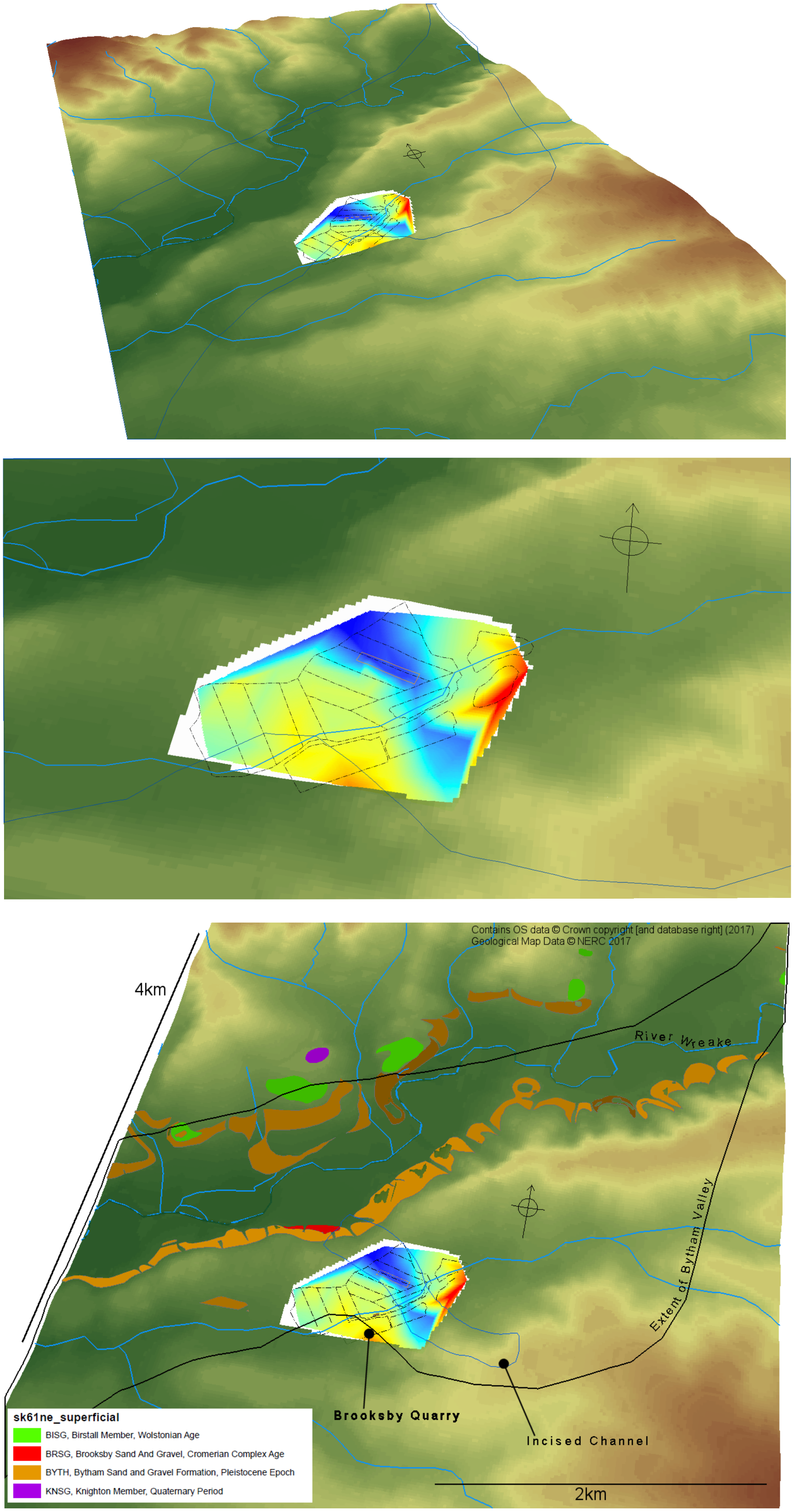


*Figure 3.5a-c***:** *Further work undertaken at Brooksby quarry by drilling boreholes and electrical tomography to further refine channel through the rockhead*

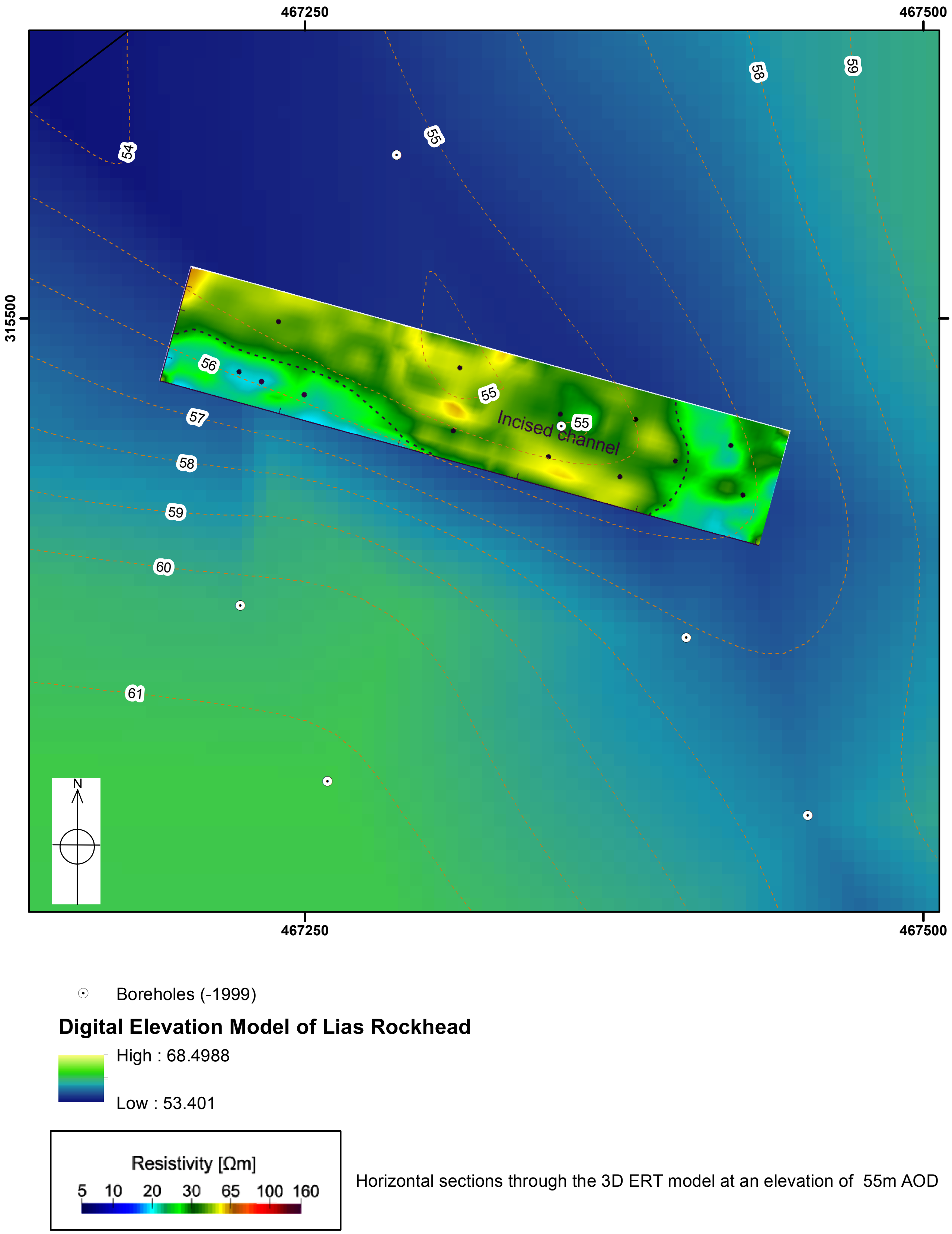


Figure 3.6: Further work undertaken at Brooksby quarry by drilling boreholes and electrical tomography to further refine channel through the rockhead

some 749 Palaeolithic stone artefacts have been recorded from the fluvial deposits (Figure 3.4). Of these, 665 have been recovered from the rejects heap, 13 from bunds, and 67 from *in situ* deposits. The majority of the *in situ* pieces have been recovered from the lower levels of the Thurmaston Member and have been within reworked deposits.

The condition of quartzite tools have been classified according to a five point scale: Mint; Sharp; Slightly Rolled; Rolled; and Very Rolled (see Keen *et al* 2006). The condition of the Brooksby quarry material ranges from Sharp to Rolled, with Mint and Very Rolled barely represented if at all. Some pieces recorded as Sharp also show gloss patination attributed to the action of wind-blown sand. The varying condition of the material relates to the depositional history of the pieces, with the fresher examples having limited transport in the Bytham River gravels. Of the artefacts, 97% have been made from quartzite and includes several hundred 'chopper-cores' (Figure 3.4). The general term 'chopper-core' follows Wymer (1999) and is used to describe cobbles with removals forming an acute platform edge. These could potentially be tools in their own right, but it is suspected that most are merely cores. Handaxes are of quartzite and also volcanic lithologies including rhyolite (Figure 3.4) and one of flint.

In 2012, the upper part of the infill of the incised channel was exposed in the quarry floor (Phases 8 and 9). The operator indicated that there would not be substantial extraction of the mineral deposit below this working floor, which comprised essentially the Brooksby Sand and Gravel. Therefore, funding was secured from Historic England to: (1) undertake an electrical resistivity tomography (ERT) survey to map the 3-dimensional sedimentary architecture and morphology of the channel; and (2) undertake two programmes of drilling (the first with shell and auger, the second by sonic methods) to calibrate the results of the ERT survey and to secure palaeoenvironmental and dating samples from otherwise inaccessible deposits. The results of this work are described fully in Beamish *et al* (2015). The tomography survey was very successful, showing the depression to be cut between 2m–5m into the clay bedrock and to include local concentrations of fine-grained sediments with the potential to yield palaeoenvironmentally significant remains (Figure 3.5a-c and Figure 3.6). The edges of the feature were also well-defined, providing an opportunity to target channel-edge areas that may have potential as areas of past occupation by early hominins. In contrast, the borehole drilling produced variable results, with high water-tables hampering sample retention. However, one core sample included a fine-grained deposit that analysis has shown to contain pollen and a single fragment of small vertebrate remains. Whilst this information was not abundant, it suggests interstadial or early interglacial environments and demonstrates further the potential to recover organic-rich temperate sediments as described by Challis and Howard (1999) and Coope (2006).

3.6. Conclusions

The Brooksby deposit model was developed around 25 years ago and continues to inform archaeological investigations at the quarry. Therefore, it has served its function and continues to be refined. The initial process and the development of an appropriate methodology was aided considerably by the enthusiasm and drive of the incumbent Senior Planning Archaeologist (Anne Graf), who had a personal research interest in the Palaeolithic and insisted that consideration of the Palaeolithic period and development of an appropriate mitigation methodology should begin early in the planning process. The development of the model was also aided significantly by the developer providing commercially sensitive, high quality, well-spaced borehole records for the site, collected by their own drilling team. Comparison of these records with the significant corpus of published literature on the regional Quaternary geology allowed site stratigraphy to be interpreted with confidence. In addition, the well-spaced drill pattern reduced problems associated with surface extrapolation of data points (for example, see Challis and Howard 2003).

Moving from evaluation for planning consent to post-application fieldwork was also accompanied by a change in archaeological contractors. Such transitions can be difficult but was aided by the new contractor having appropriately qualified in-house staff with Palaeolithic interests who recognized the need to continue with the methodological approach. This is tremendously important since the appointment of an organisation without Palaeolithic expertise could have led to dilution of this strategy.

Acknowledgements

The work described in this chapter as well as continued funding for archaeological investigations at the site is provided by Lafarge Redland Aggregates Ltd and is gratefully acknowledged. Historic England provided additional funding for geophysical mapping and sampling of the Brooksby Sand and Gravel. Thanks are due to Anne Graf (formerly Senior Planning Archaeologist for Leicestershire County Council [LCC]), Richard Clark, the current Principal Planning Archaeologist for LCC and Dr Isabel Lisboa (Archaeologica Ltd), who is consultant to the client. Thanks also to Jonathan Chambers (British Geological Survey) who undertook the ERT survey, Professor Danielle Schreve (Royal Holloway, University of London) for co-ordinating the palaeoenvironmental survey and Mathew Schlemmer (Brooksby Quarry Manager) for facilitating site access and logistics associated with ongoing fieldwork.

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Constructing a geoarchaeological deposit model: Brooksby

Assess pre-existing data

- British Geological Survey mapping
- Confidential client geotechnical records (boreholes)
- Significant regional geoarchaeological literature

Develop rationale for model construction and key aims andobjectives

- Understand Pleistocene sedimentary architecture and distinguish depositional environments
- Identify potential location and distribution of units where cultural and environmental archaeology likely to be preserved.

Can the deposit model be constructed using pre-existing data?

Yes

Commission further ground investigations, including:

- Additional purposive boreholes but only to sample for palaeoenvironmental remains, not to enhance model development

Construct deposit model comprising of one or more of the following:

- Interpolation of key stratigraphic unit upper and lower bounding surfaces
- Representative cross-sections

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- ERT, shell and auger and sonic drilling used to refine deposit model

Revise final product

Deposit model updated and further reports issued.

Archive and reuse

Data and reports archived with University of Leicester Archaeological Services

4. Modelling Pleistocene deposits and the Palaeolithic archaeological potential of a site at Pan Lane, Newport, Isle of Wight

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Abstract

Geoarchaeological investigations were carried out at the site of Pan Lane, Newport, Isle of Wight, to determine the impact of the proposed construction of a new supermarket on Pleistocene fluvial deposits. The site lies 150m south of Great Pan Farm, where gravel extraction during the first half of the 20th century yielded 140 lithic artefacts dating from the Middle Palaeolithic. Geoarchaeological test-pitting prior to this investigation had predicted that the Great Pan Farm gravel (mapped as Terrace 1) passed to the west of the (Pan Lane) site, with three earlier river terraces crossing it (Terraces 2-4). As part of the present investigation, a database of lithostratigraphic data was used to construct a deposit model which informed the positioning of 12 new geoarchaeological test-pits and 3 boreholes. Lithostratigraphic data from the integrated test-pit and borehole model demonstrated that only one Pleistocene terrace (T2) would be impacted by groundworks for an access road and roundabout. Optically-Stimulated Luminescence (OSL) dating of Terrace 2 suggests that it spans the period between 120,000 and 55,000 years BP, when humans are likely to have been absent from Britain. Thus, through a combination of deposit modelling and OSL dating, the geoarchaeological investigations demonstrated that the proposed development would not adversely impact on deposits likely to contain *in situ* Palaeolithic archaeological remains.

4.1. Introduction

Geoarchaeological investigations were carried out at Pan Lane, Newport, Isle of Wight, to determine the impact of a proposed supermarket development on possible Pleistocene fluvial deposits (Figures 4.1a-b). The site comprised 3.9ha of land on the east flank of the Medina valley at an altitude of between 25m OD and 9m OD. British Geological Survey (BGS) mapping indicated that the underlying geology comprised Eocene bedrock deposits of the London Clay Formation across the extreme southern part of the site and undifferentiated Bracklesham and Barton Groups in the northern area (BGS 2015a). However, no superficial deposits were recorded by the BGS across the site.

Despite the absence from BGS mapping of Pleistocene sediments, the Pan Lane site was deemed to have the potential for the preservation of Palaeolithic archaeological remains. This hypothesis was based on the site's location 150m south of the Great Pan Farm gravel pit, albeit on a more elevated terrace formation (>3m higher). Aggregate extraction at Great Pan Farm between 1912 and the 1920s had yielded 140 artefacts of presumed Middle Palaeolithic age, making it the richest Palaeolithic site on the Isle of Wight (Poole 1925; Shackley 1973). Prior to the investigation reported here, two geoarchaeological test-pit surveys had been carried out (Archaeology South-East 2005, 2006; Oxford Archaeology 2005) in response to development proposals encompassing the site (Figure 4.1c: 'ASE' and 'OX' test-pits). Results from these studies suggested the presence of four Pleistocene fluvial aggradations designated Terraces 1-4, ascending progressively in height from the lowermost Great Pan Farm Terrace (T1). Oxford Archaeology (2005) modelled the distribution of the two higher terraces (T3 and T4) as an approximately 80m wide band trending north-north-east to south-south-west across the site, with Terrace 2 clipping the westernmost site boundary. However, neither of the former geoarchaeological investigations showed

Comparative data table of this deposit model	
Deposit model location	Newport, Isle of Wight (NGR: 50590 88400)
Depositional environment	Eastern flank of the Medina valley, where Pleistocene fluvial terrace(s) overly Eocene bedrock
Size of deposit model	The entire site is 3.9ha in extent; the deposit models varied in size between 1.9ha and 1.3 ha
Data collection strategies	Analysis of existing geotechnical borehole/test-pit logs and geoarchaeological test-pits collected for previous site investigation works; 12 new geoarchaeological test-pits were excavated, together with 3 geoarchaeological boreholes drilled with a dynamic coring device (Pioneer 2 rig)
Position in the archaeological process	Dedicated evaluation following production of a Desk-Based Assessment; this evaluation was conducted separately from the evaluation of archaeological remains
Reason for deposit model construction	To predict the location of Pleistocene sediments with high archaeological potential that would be impacted by groundworks
Archaeological question	Age, type and mode of formation of Pleistocene deposits, which might contain Palaeolithic remains
Software and modelling process	All lithological data collected prior to and during the project were inputted into RockWorks 15. That software was used to produce composite cross-sections and deposit models; the models derived from this work were viewed with respect to topography and the proposed groundworks by means of ArcGIS 10.1
Outputs from the deposit model	Modelled surfaces of the upper contact of periglacial solifluction deposits (Head) and fluvial terrace gravels, together with modelled thicknesses of Head and fluvial deposits

the Great Pan Farm gravel (T1) to extend to the Pan Lane site. The previous investigations had attempted to date the lower two terraces (T1 and T2). A ^{14}C date of >43,500 cal. BP was obtained from peat recovered from test-pit ASE14 within Terrace 1 sediments to the west of the site (Archaeology South-East 2006). In addition, two optically-stimulated luminescence (OSL) dates on sandy deposits recorded in a test-pit through Terrace 2 (OX 1) yielded age estimates in the *c* 31,000-47,000 BP age range (Figure 4.1c; Schwenninger 2005).

4.2. Aims

Given the inferred distribution of Pleistocene fluvial sediments within the Pan Lane site, the proximity of the Pan Farm quarry and the potential for the survival of archaeologically important Palaeolithic deposits (Wenban-Smith *et al* 2014), the following aims were set out for the geoarchaeological investigations:

- Differentiate, map and model the extent and thickness of Pleistocene fluvial terraces and overlying mass-movement deposits within the site;
- Determine the relative and absolute age of the Pleistocene fluvial deposits within the site;
- Assess the Palaeolithic archaeological and palaeo-environmental potential of any terrace formations identified within the site;
- Assess the impact of the proposed groundworks on the Palaeolithic archaeological resource.

4.3. Methodology

In order to address these aims, the geoarchaeological study at Pan Lane was undertaken in four stages:

Stage 1 saw the construction of a RockWorks 15 database (RockWare 2013) containing existing lithostratigraphic data and the development of a project geographic information system (ArcGIS 10.1).

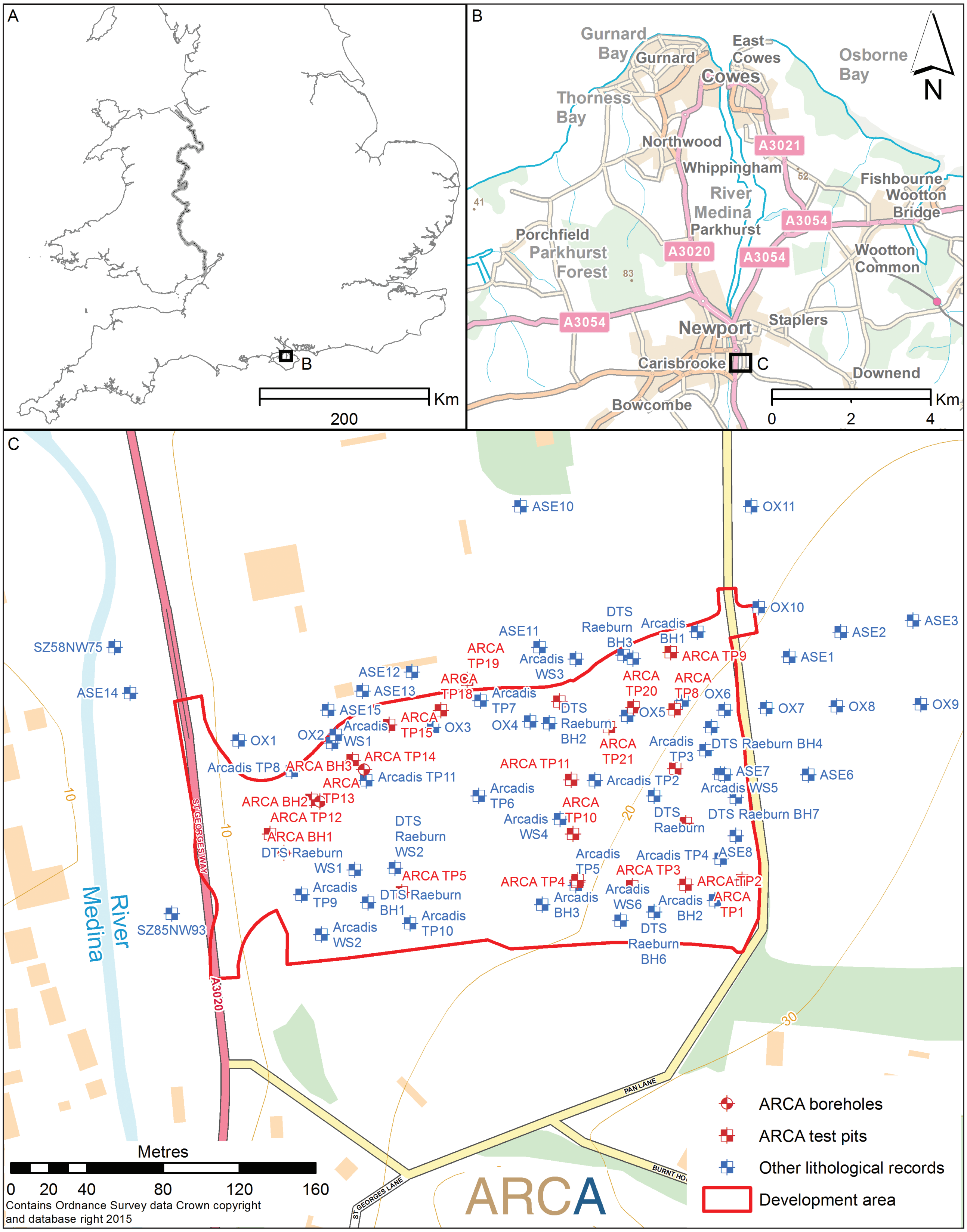

Figure 4.1: a. Location of the Isle of Wight in southern Britain; b. Newport and the northern part of the Isle of Wight; and c. the Pan Lane site showing the location of groundworks for the development, previous and current boreholes and test pits

Geoarchaeological test-pit descriptions from the Archaeology South-East (2005) and Oxford Archaeology (2005) studies, together with logs from previous geotechnical borehole surveys (Arcadis 2012; DTS Raeburn 2015) and records from the BGS borehole database (BGS 2015b), were combined in RockWorks. The database file was also read into the ArcGIS project, enabling comparison of the lithostratigraphic records with topographic data and the planned supermarket footprint. RockWorks was then used to plot a series of draft composite cross-sections, which were used to assess the impact of proposed groundworks on the Quaternary deposits.

Stage 2 comprised the excavation of 12 geo-archaeological test-pits (see 'ARCA TP1-12' in Figure 4.1c), positioned in order to sample: (1) areas that were not covered by previous geoarchaeological test-pitting; (2) areas where prior test-pits or boreholes had indicated the presence of Pleistocene fluvial sediments; and (3) areas that were to be affected by the proposed groundworks. Test-pit locations were identified within ArcGIS, and coordinates were uploaded to a Leica System 1200 RTK GPS; the GPS was used both to locate test-pit locations in the field and to record their surface elevations. Test-pits measured 1.5m by 1.5m in size and were dug through the entire Quaternary sequence (a maximum of 4m below ground level) by a 360^{o} tracked excavator; sediments were removed in a series of 0.2m-0.3m thick spits under the supervision of a geoarchaeologist. Approximately 20L samples of each spit of Pleistocene material were passed through a 10mm sieve to test for the presence of Palaeolithic artefacts, although none was found. A representative face of each test pit was described with respect to its sedimentology; these descriptions, together with associated geopositional data, were transferred to the RockWorks database after the completion of fieldwork.

Stage 3 saw the drilling of three boreholes ('ARCA BH1-3') in locations where the test-pit data suggested the presence of Pleistocene fluvial sediments. The boreholes were placed immediately adjacent to the Stage 2 test-pits (Figure 4.1c) and were drilled by a geotechnical contractor using a Pioneer 2 dynamic sampling rig, which collected continuous cores of 112mm diameter. The 1.5m long Perspex sleeves containing the cores were extruded directly from the sampler into black light-tight plastic bags, which were then carefully labelled. On completion of the drilling, the cores were transported to the Luminescence Dating Laboratory at the University of Gloucestershire. Cores containing Pleistocene fluvial sediments, identified from descriptions of adjacent test pits, were cut open under controlled light conditions. Three slices of 50mm thickness were then sub-sampled from two of the cores for OSL dating (as described in Wilkinson *et al* 2016). All of the cores were taken to ARCA's laboratory at the University of Winchester. Their lithology was described and sediment descriptions were added to the RockWorks database. Sub-samples were taken opportunistically from fine-grained sediments within the cores for biostratigraphic assessment (pollen and molluscs), although no floral or faunal material was found to be preserved.

Stage 4 comprised data integration. Lithological descriptions from previous stages of work were reviewed and the recorded units were grouped for interpretative purposes into mappable stratigraphic members and formations (North American Commission on Stratigraphic Nomenclature 2005; 'Stratigraphy' *sensu* RockWare 2013). These latter categories formed the basis of 2-dimensional and 3-dimensional deposit models constructed within RockWorks, which were then read into ArcGIS to enable comparison with the areas in which groundworks were proposed.

4.4. Interpretation

Five stratigraphic units were identified on the site and are described below in order of their formation. Their stratigraphic relationships are illustrated in Figure 4.2.

Bracklesham and Barton Groups: compact sands (Bracklesham Group) and clays (Barton Group). These bedrock deposits were encountered at the ground surface in the southern part of the site, but at a depth of up to 3.8m below ground level (BGL) elsewhere. These Eocene strata are separated from the Quaternary sequence outlined below by an unconformity.

Pleistocene fluvial gravel (Terrace 2): clast- and matrix-supported flint gravels with lenticular sand units, recorded in the western part of the site in ARCA test-pits (TP12, 13, 14, 15 and 18) and ARCA boreholes (BH1, 2 and 3; Figure 4.3). The elevation of the upper contact ranges between 11.87m OD (0.9m BGL) in ARCA BH15 to 9.90m OD (2.62m BGL) in ARCA BH2; the thickness of the unit varies between 2.1m (ARCA TP13 and 15) and 0.38m (ARCA BH3).

Head: the BGS (2015c) defines Head as a Quaternary polymict deposit composed of gravel, sand and/or clay-sized material depending upon the upslope source and is usually taken to mean the product of periglacial solifluction processes (French 2007, 332). Material described as Head on the Pan Lane site comprises poorly-sorted sands, silts and clays and matrix-supported gravels. The deposit is predominantly composed of fine-grained material derived from local Eocene units, while the gravels are of flint and derive from the White Chalk Subgroup (*sensu* BGS 2015c) to the south of the site. Such Head deposits infill a *c* 40m wide and 130m long gully in the northern and eastern part of the site, but also forms aprons of sediment at breaks of slope (Figures 4.2 and 4.3).

Colluvium: this term is used here to describe the product of hillslope processes operating during the Holocene and therefore mostly the result of cultivation (Wilkinson 2009). The sediment comprises poorly-sorted sandy clays and gravels and was found across most of the site. Colluvial deposits generally increased in thickness

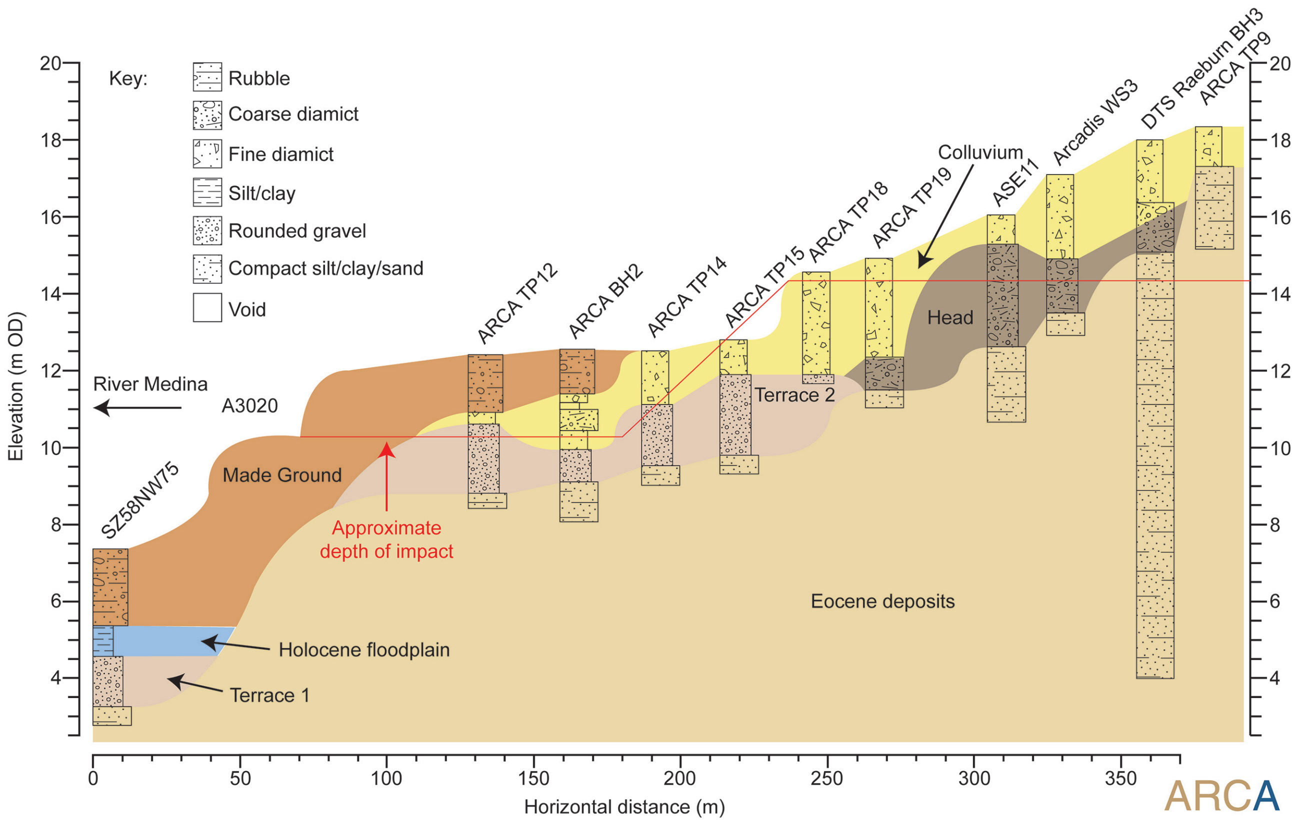

Figure 4.2: Composite west (left) to east (right) cross-section through the Pan Lane site

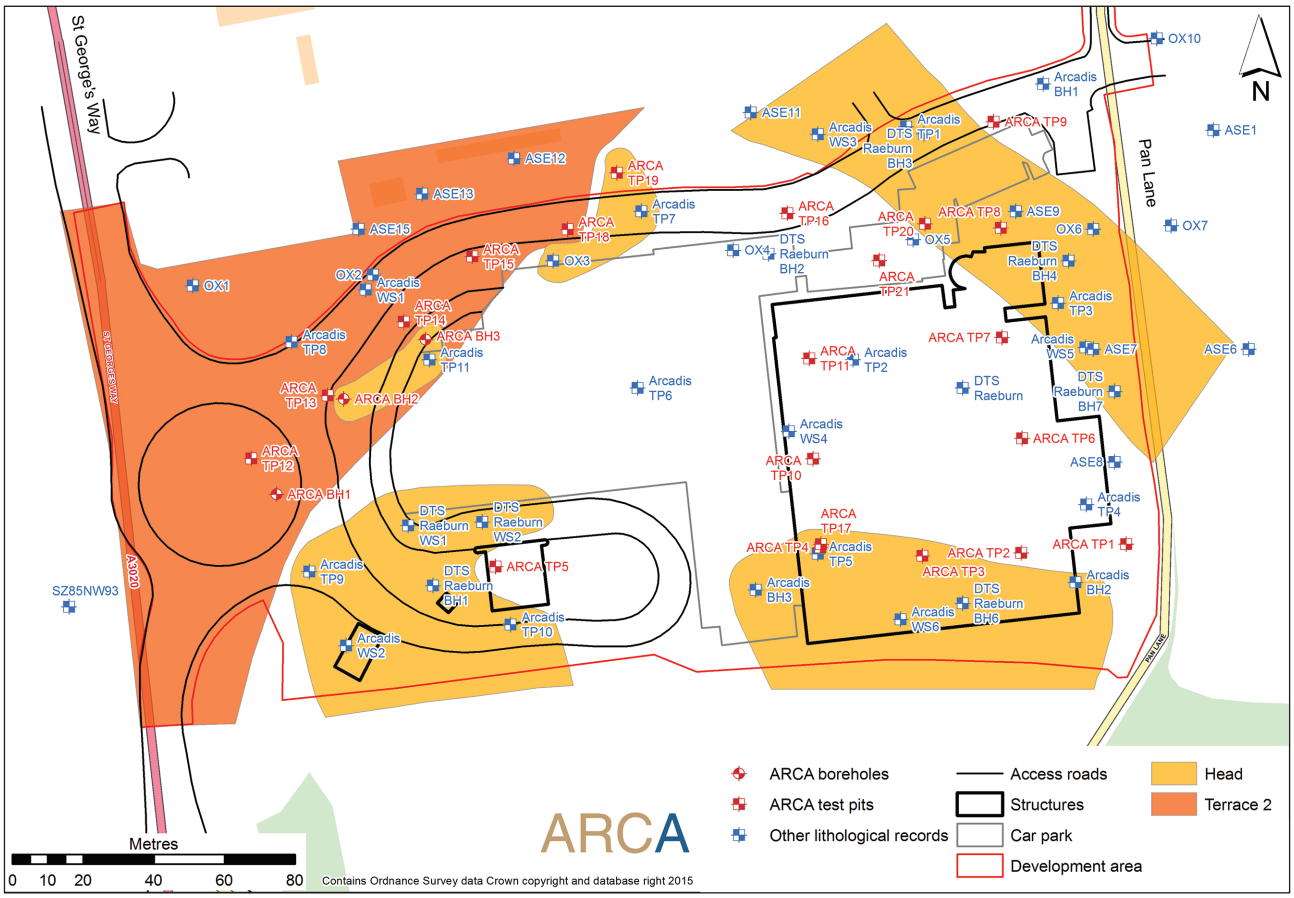

Figure 4.3: An interpretation of the distribution of Pleistocene deposits on the Pan Lane site

downslope from east to west, and attained a maximum thickness (2.8m) where they overlaid Head deposits filling the gully in the north-west corner of the site. Colluvium must have been removed to create the football pitch that had previously occupied the western part of the site (and had been levelled with 'Made Ground'; see below).

Made Ground: deliberately deposited gravels, sands and clays, up to 1.55m thick and containing abundant 20th century artefacts and building materials, were found as 'fill' in the west of the site (Figure 4.3). This material had clearly been used both to level the ground and to provide a stable surface for the football pitch at this location.

The data reviewed above demonstrate that fluvial gravels crop out in the western part of the site. Coarse-grained deposits found elsewhere, and interpreted as alluvial sediments in earlier geoarchaeological investigations, are now considered to represent Head deposits. The suggestion by earlier investigators that three fluvial terraces crop out at altitudinally distinct levels is most likely the product of interpolation based on relatively few data points from the east and north margins of the site.

The composite cross-sections, such as Figure 4.2, that result from the present work demonstrate that the fluvial gravels recorded in the west of the site belong to a single terrace (T2) that is altitudinally distinct from the Great Pan Farm gravel (T1). The deposit models constructed from the integrated stratigraphic data suggest that groundworks associated with the construction of a roundabout and access road to the supermarket would intersect with Terrace 2 (Figure 4.4). They also indicate that the entire thickness of the Quaternary sequence, including 2.1m of fluvial gravels in the vicinity of ARCA TP13, would be removed in the vicinity of the proposed roundabout in the west of the site and in a sump feature immediately to the north (Figure 4.5).

The potential for Palaeolithic archaeological remains to be preserved within Terrace 2 is based upon the nature and energy of the depositional environment and the absolute ages of the stratum on the site (English Heritage 1999; Gamble *et al* 2008). The former determines whether any archaeological materials are likely to be preserved *in situ*, and the latter whether hominins were present in Britain at the time of terrace formation. The sedimentary characteristics of Terrace 2, as observed from test-pits and boreholes, suggest that while fine-grained deposits do exist, they are small-scale and are likely to represent only minor accumulations that were formed during declining flow conditions. In other words, there are no indications from site investigations of stable ground surfaces on which hominins might have been active within the deposits of Terrace 2.

OSL dating of three samples from Terrace 2

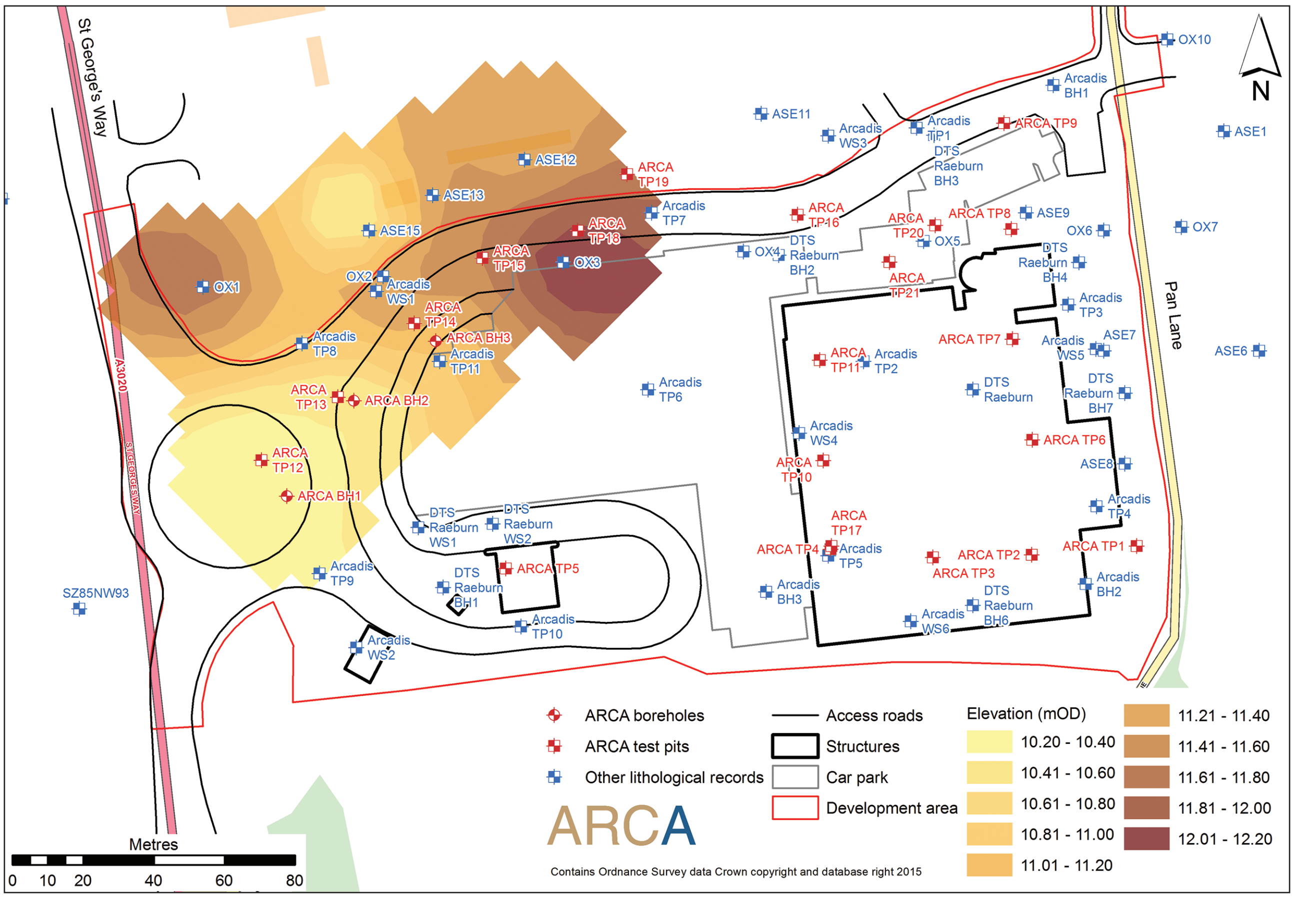

Figure 4.4: Modelled surface of Terrace 2 within the Pan Lane site. The model was constructed using a kriging algorithm based on the nearest eight neighbours, while a 5% distance filter was also applied (ie pixels more than 5% of the longest project dimension [28.5m], from a borehole or test pit containing the particular stratigraphic layer are not incorporated in the model)

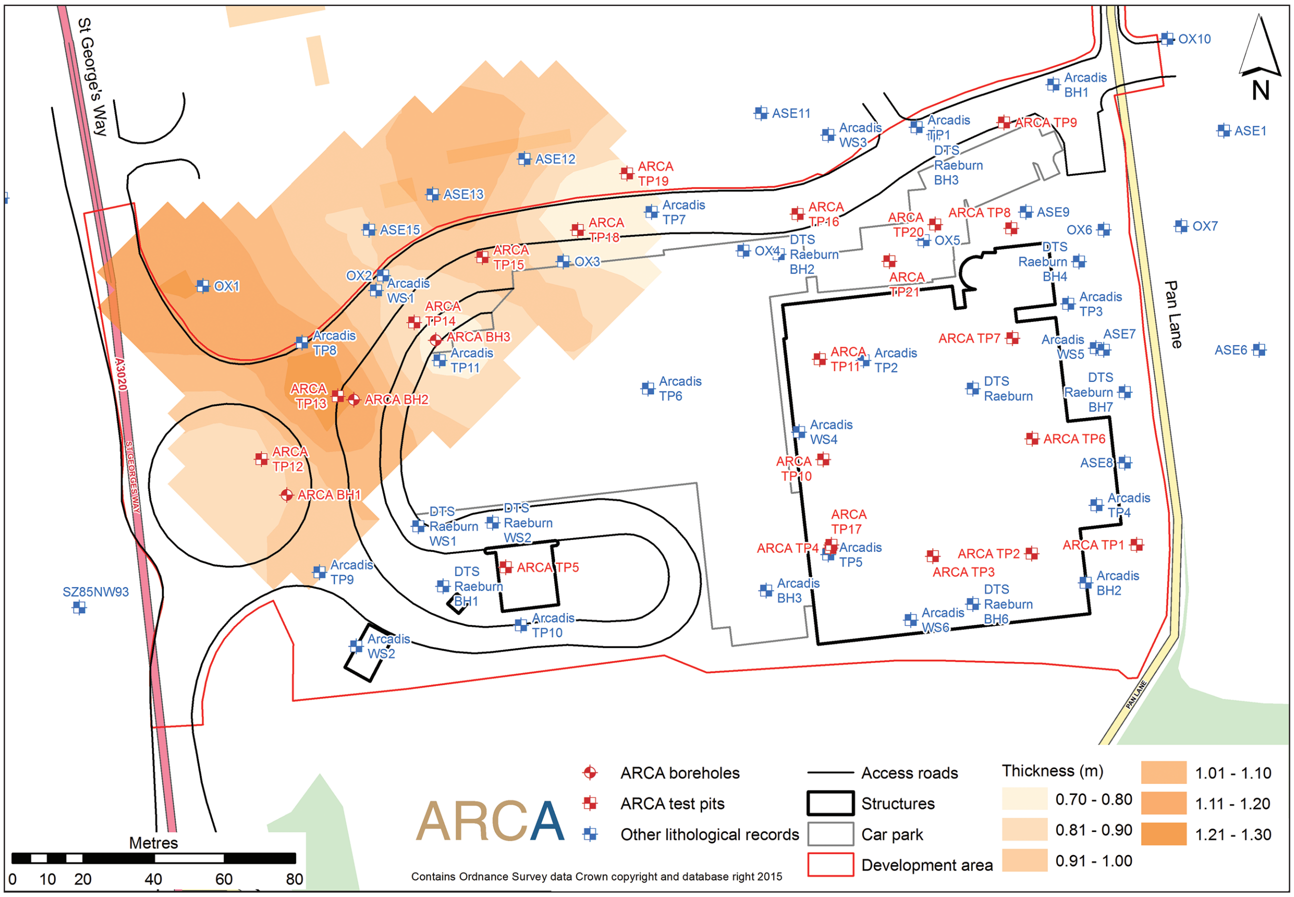

Figure 4.5: Modelled thickness of Terrace 2 within the Pan Lane site (the modelling algorithm and settings were the same as outlined for Figure 4.4)

resulted in age estimates ranging from 358 ± 44 ka BP (GL 15101) to 83 ± 7 ka BP (GL 15100), although it must be emphasised that there is significant uranium disequilibrium associated with GL 15100 and particularly GL 15101 (Table 4.1). Accepting that GL 15099 (from the base of the terrace) provides an accurate age estimate and that the sedimentological evidence suggests aggradation under periglacial conditions, the age range at two standard deviations could signify accretion of Terrace 2 from Marine Isotope Stages (MIS) 5d-4, around 120,000 to 89,000 years BP. Furthermore, based on OSL measurements from the nearby sites of Bembridge and Priory Bay, Schwenninger (2005) suggested that the real age of OSL samples from test-pit OX1 could be in the region of 55,000 to 60,000 years BP, corresponding with early MIS 3; this would place the overall formation of Terrace 2 during the interval from MIS 5d to early MIS 3 (120,000-55,000 years BP).

Currant and Jacobi (2001) have correlated mammalian biozones with both the marine isotope stage framework and the evidence for hominin activity in Britain (Table 4.2). Late MIS 5 (ie sub-stages 5d-5a) corresponds with the Bacon Hole Mammal Assemblage Zone (MAZ) and MIS 4 with the Banwell Bone Cave MAZ, neither of which are characterised by *in situ* Palaeolithic material (Currant and Jacobi 2001). Faunal assemblages of the preceding Joint Mitnor Cave MAZ of MIS 5e (the last 'Ipswichian' interglacial) have also not been found alongside Palaeolithic artefacts. In contrast to earlier interglacials such as MIS 7, MIS 9 and MIS

Table 4.1: Results of the OSL dating from Pan Lane

Borehole and depth (m BGL)	**Lab. code**	**Total Dr (Gy ka^{-1})**	**De (Gy)**	**Age (ky BP)**
BH2 3.37-3.42m	GL 15099	-1.31±0.09	141.0±6.2	107± 9
BH1 2.05-2.10m	GL 15100	0.78±0.06	65.0±2.5	83±7
BH1 2.85-2.90m	GL 15101	0.96±0.07	342.2±32.7	358±44

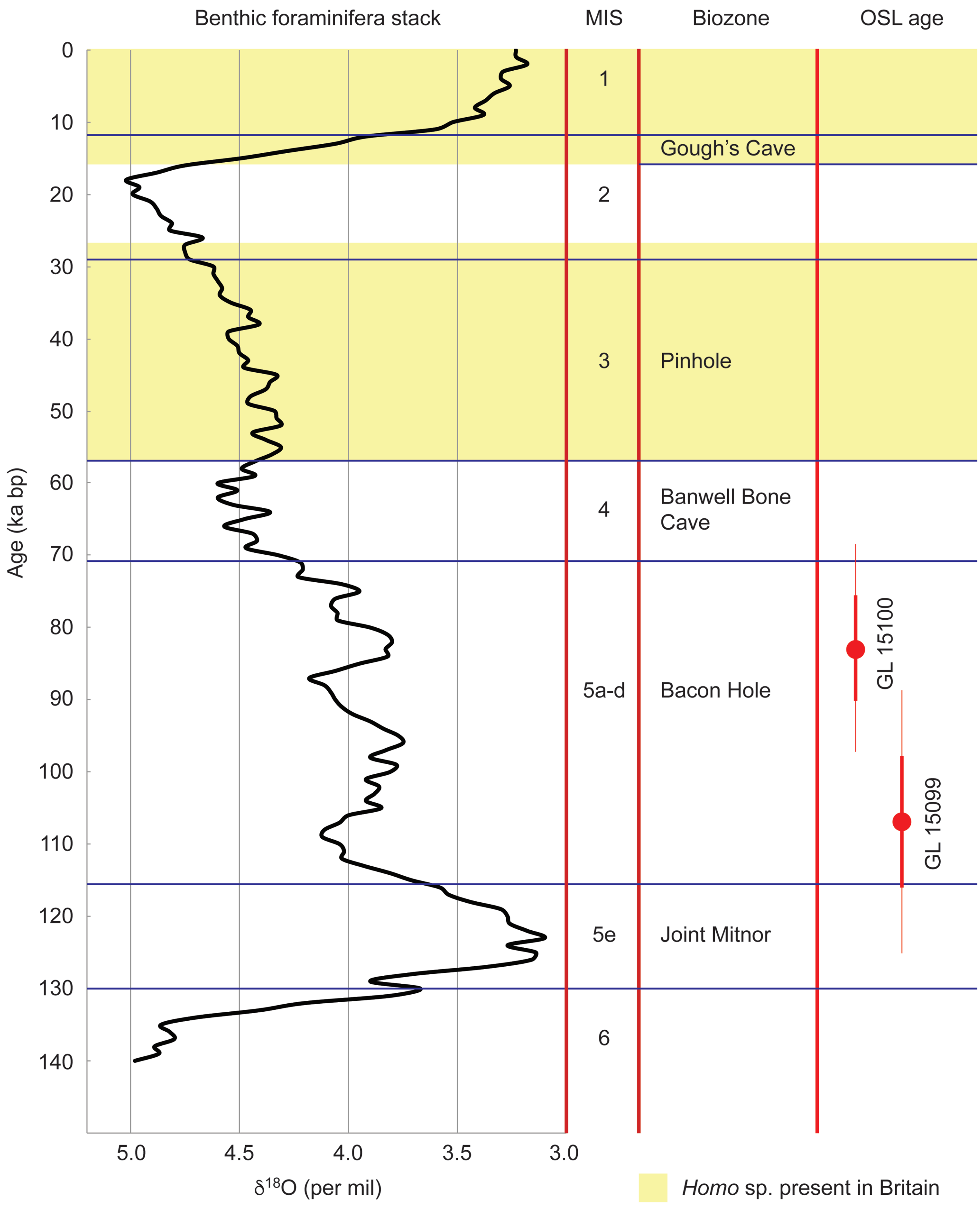

Figure 4.6. Pan Lane OSL dates correlated with Lisiecki and Raymo's (2005) stack of 57 globally distributed benthic $\delta^{18}O$ records, Currant and Jacobi's (2001) British mammalian biozones and periods when Britain was occupied by humans

Table 4.2: Extract of Currant and Jacobi's (2001) Late Pleistocene mammalian biozone system and evidence for human activity in Britain

MAZ	Characteristic large mammals	MIS	Archaeology
Pin Hole	Woolly mammoth, Woolly rhinoceros, Horse, Reindeer, Bison, Lion, Brown bear, Wolf	3	Yes
Banwell Bone Cave	Bison, Reindeer, Wolf, Brown bear, Wolverine	4	No
Bacon Hole	Mammoth, Roe deer, Red deer, Straight-tusked elephant, Bison	5d-a	No
Joint Mitnor	Hippopotamus, Red deer, Fallow deer, Giant deer, Lion, Straight-tusked elephant, Bison	5e	No

11, in which hunter-gatherer communities are known to have been present in Britain. Sutcliffe (1995) has argued that Britain was cut off from continental Europe early in the last interglacial before hominins could colonise it. Although reconnected to mainland Europe in MIS 5d as a result of falling sea levels, cooling climates and aridity meant that Britain was probably inhospitable. Conditions became colder still in MIS 4, and hence Britain was only recolonised during MIS 3 (Pettitt and White 2012). At only one site, close to the M2/A2 junction at Dartford in Kent, has evidence been found that Britain might have been occupied by hominin groups during MIS 5d-5b; the evidence comprises two artefacts recorded at the interface of two colluvial units, the later of which was dated by OSL to between 115.9 ± 9.1 ka BP (X3126) and 88.7 ± 6.5 ka BP (X3125B; Wenban-Smith *et al* 2010). Despite the evidence from Dartford, the balance of probability would favour formation of Terrace 2 during a period in which hominins were absent from Britain (Figure 4.6).

4.5. Conclusions

The deposit models produced for the Pan Lane development demonstrate that Pleistocene fluvial deposits would be impacted by proposed groundworks in the western part of the site. Furthermore, a model of deposit thickness showed that the entire Quaternary sequence would be removed in an area associated with a planned roundabout and access road. However, geoarchaeological investigations of the stratigraphy of the fluvial gravels cropping out on the site indicates that they belong to a single fluvial terrace (T2) and that the deposits are stratigraphically earlier than the artefact-bearing Great Pan Farm gravel (T1). Furthermore, OSL dating of Terrace 2 suggests that it had formed within the MIS 5d to MIS 3 time interval (120,000–55,000 years BP). The reconstructed depositional environment of the fluvial gravels comprised a periglacial braided river system and the lack of fine-grained sediments suggest that *in situ* Palaeolithic remains are unlikely to be found under such taphonomic conditions (English Heritage 1999; Wilkinson 2002). Furthermore, the age of the sediment stack coincides with a period when hominins are unlikely to have been present in Britain (Currant and Jacobi 2001; Sutcliffe 1995). As a result, the fluvial gravels were deemed to have minor archaeological significance and the development proceeded without further archaeological conditions.

Despite the negative outcome regarding the presence of Palaeolithic archaeological remains, the strategy used to investigate Pleistocene deposits on the site proved very successful. Test-pitting in a situation where the Quaternary stratigraphy was less than 4m thick enabled the lithostratigraphy to be examined rapidly, while providing a sufficiently large window to enable the genesis of the sediments to be determined. Learning from previous archaeological campaigns in the area where samples had been collected from open sections in test-pit walls, the approach of using a drilling rig equipped with a large-diameter core sampler to collect samples for OSL dating, biostratigraphic and sedimentary analysis, worked well. Problems were encountered with at least one of the OSL dates and there was no biological preservation within the gravels, but the samples in both cases were better constrained, could be examined in an undisturbed state in the laboratory, and suffered less from potential problems of contamination. Indeed, the geoarchaeological investigations at Pan Lane provided the detailed information required to demonstrate that the development would not adversely impact deposits containing important *in situ* Palaeolithic archaeological remains, while also proving to be cost-effective. However, arguably the most significant lesson of the present geoarchaeological study concerns the resolution of understanding of the stratigraphic deposits. Previous geoarchaeological studies had suggested three Pleistocene fluvial terraces on the basis of 17 sediment records from the north and east of the site and its immediate surroundings (equating to 3.4 records per hectare). Drawing on the earlier geoarchaeological works, intervening geotechnical studies and newly commissioned test-pit and borehole interventions, the current study had access to 63 records across the entire site (12.6 records per hectare). The resulting deposit model allowed the identification of a single terrace that could be mapped across 1.3ha of the western part of the site (Terrace 2). In short, the robustness of geoarchaeological inference derived from a deposit model is directly proportional to both the resolution of the data on which the model is built and the spatial spread of data points (test-pits, boreholes, etc). It is imperative that the builders of deposit models communicate such constraints to the relevant stakeholders and do not conceal uncertainty behind attractive illustrative outputs.

Acknowledgments

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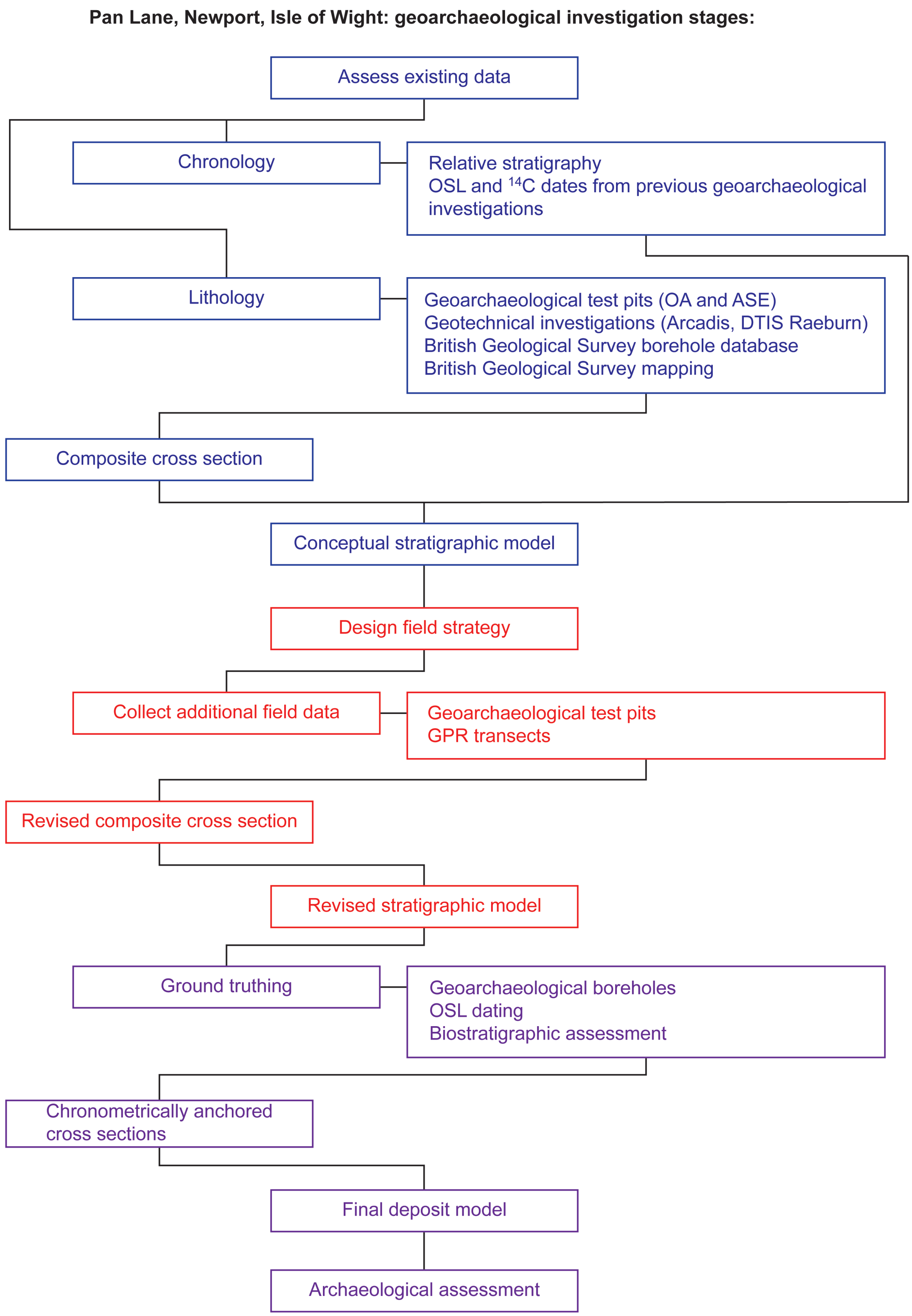

Pan Lane, Newport, Isle of Wight: geoarchaeological investigation stages:
Assess existing data
Chronology
Relative stratigraphy
OSL and ¹⁴C dates from previous geoarchaeological investigations
Lithology
Geoarchaeological test pits (OA and ASE)
Geotechnical investigations (Arcadis, DTIS Raeburn)
British Geological Survey borehole database
British Geological Survey mapping
Composite cross section
Conceptual stratigraphic model
Design field strategy
Collect additional field data
Geoarchaeological test pits
GPR transects
Revised composite cross section
Revised stratigraphic model
Ground truthing
Geoarchaeological boreholes
OSL dating
Biostratigraphic assessment
Chronometrically anchored cross sections
Final deposit model
Archaeological assessment

SECTION 3

Modelling along linear corridors

5. Bexhill to Hastings link road, East Sussex: a geoarchaeological deposit model on the Combe Haven and surrounding valley sequences

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Abstract

As part of a proposed new link road between Bexhill and Hastings, in East Sussex, a deposit model was created in order to develop an interpretative framework to investigate the archaeological potential of a series of river valleys and associated bedrock ridges of Ashdown Sands and Wadhurst Clays. The 5.6km scheme skirts around a series of alluvial sequences that have been deposited in a low-lying former coastal inlet of the Combe Haven. A staged approach was adopted using multiple data-sources from geotechnical investigations and archaeological boreholes, test pits, geophysics and trenching. The models helped to define more closely and to characterise the palaeotopography of the area impacted by the scheme, its Holocene sedimentary sequences and their archaeological potential. The model produced a zonation of landscape areas, identifying valley edge environments containing densely stratified, well-preserved, early prehistoric remains. This model allowed these interface zones and subsurface features to be targeted during evaluations, rather than adopting a standard blanket sampling approach across the valley sequences.

5.1. Introduction

During the planning stages for a new link road between Bexhill and Hastings in East Sussex, a deposit model was proposed for a landscape which incorporated a series of river valleys and adjacent low bedrock ridges of Ashdown Sands and Wadhurst Clays (Figures 5.1 and 5.2). The new road skirts around the main Combe Valley Countryside Park including the Filsham Reedbed Local Nature Reserve (LNR) and crosses a number of watercourses that flow into the Combe Haven (namely the Combe Haven, Watermill, Powdermill and Decoy Pond streams). During the early stages of the project the impacts of the scheme were not defined, as it was a design and build project. The project involved the building of a series of road embankments across the river valleys and ground reduction of the bedrock ridges to reduce the visual impact of the scheme on the LNR. The embankments were designed to be rafted over the wetlands and supported by a series of concrete piles. Activities which impacted on the landscape and potentially on archaeological remains were both direct, from the construction itself, and indirect, from activities such as the construction of balancing ponds, landscaping and tree planting.

Standard blanket sampling of the valley sequences using traditional trial trenching was considered but thought to be prohibitively expensive and problematic due to the high water-tables recorded within the valleys. An alternative and more appropriate approach adopted by Oxford Archaeology at the request of the County Archaeologist was to develop a deposit model for the scheme in order to provide an effective and cost-efficient targeted approach to investigating these alluvial sequences.

5.2. Aims and objectives

The deposit model was developed during the planning stages to characterise the archaeological and palaeoenvironmental potential of the valley sequences and was updated throughout the life of the project. The objectives of the deposit model can be summarised as:

- To identify any buried topographic features that may have been the focus of early prehistoric activity;
- To help to identify potential archaeological risks to the project;
- To develop a landscape model which could be used to inform and develop suitable evaluation and mitigation strategies.

Comparative data table of this deposit model	
Deposit model location	Bexhill, UK (NGR: TQ 7560 1070)
Depositional environment	Alluvial sequences of the Combe Haven and surrounding valleys
Size of deposit model	The deposit model covered a 5.6km route embracing *c* 135 Ha
Data collection strategies	A mixture of geotechnical investigations, purposive boreholes and test pits, conductivity survey, evaluation trenches and excavation areas
Position in the archaeological process	Pre-fieldwork, evaluation and mitigation strategies
Reason for deposit model construction	To model the palaeotopography and Holocene sedimentary sequence
Archaeological question	Define the depth of the Holocene sediment sequences and identify likely locations and horizons of archaeological remains
Software and modelling process	The data was inputted and correlated in Rockworks 14. A series of modelled surface and representative sections were produced and exported to GIS and Illustrator
Outputs from the deposit model	A series of topographically modelled surfaces and representative cross-sections. Conductivity mapping, showing geomorphological and archaeological features. Zonation of the site into different landscape areas, with a statement of archaeological potential for each.

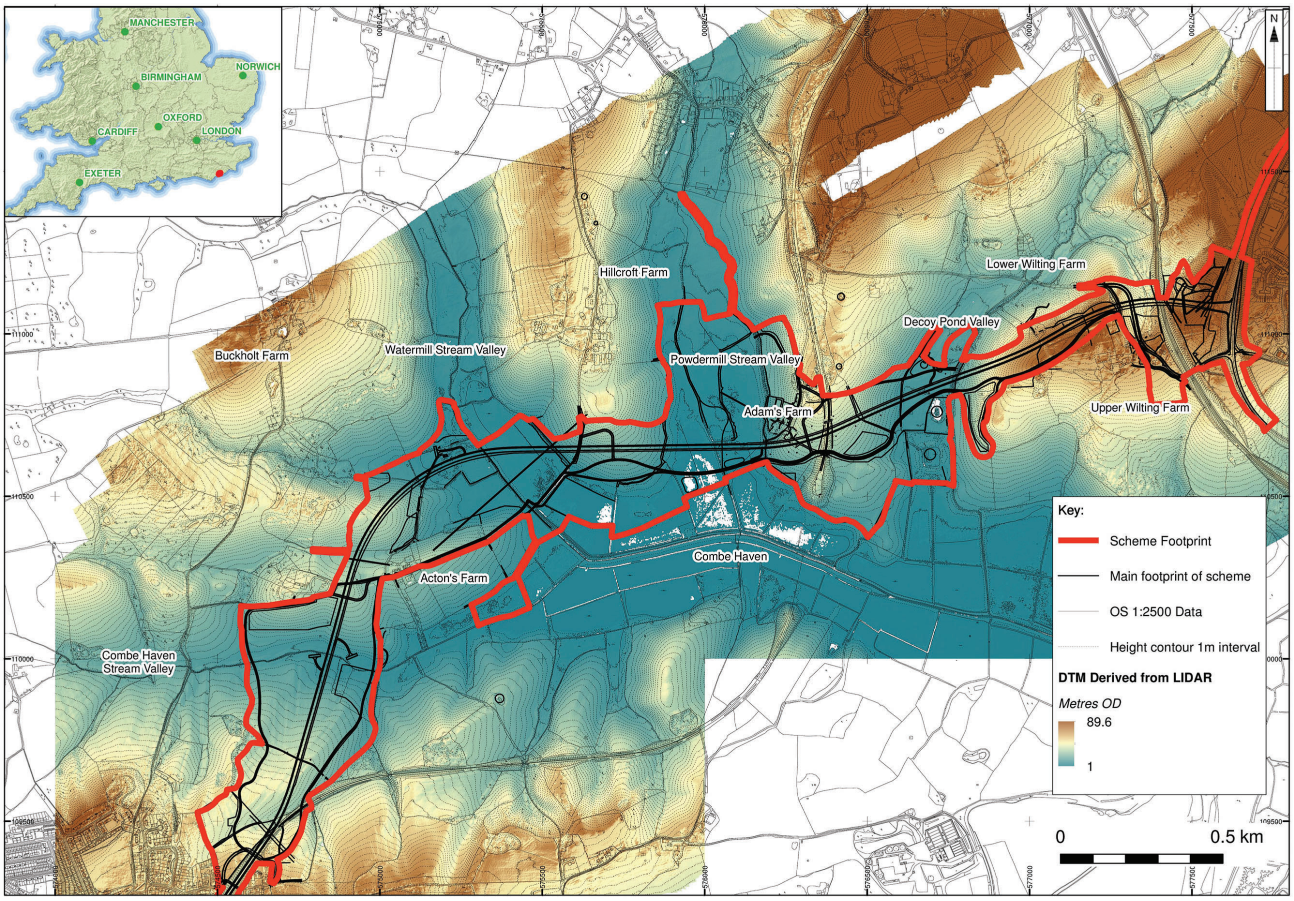


Figure 5.1: Location of the Bexhill to Hastings Link Road and its relationship to topography

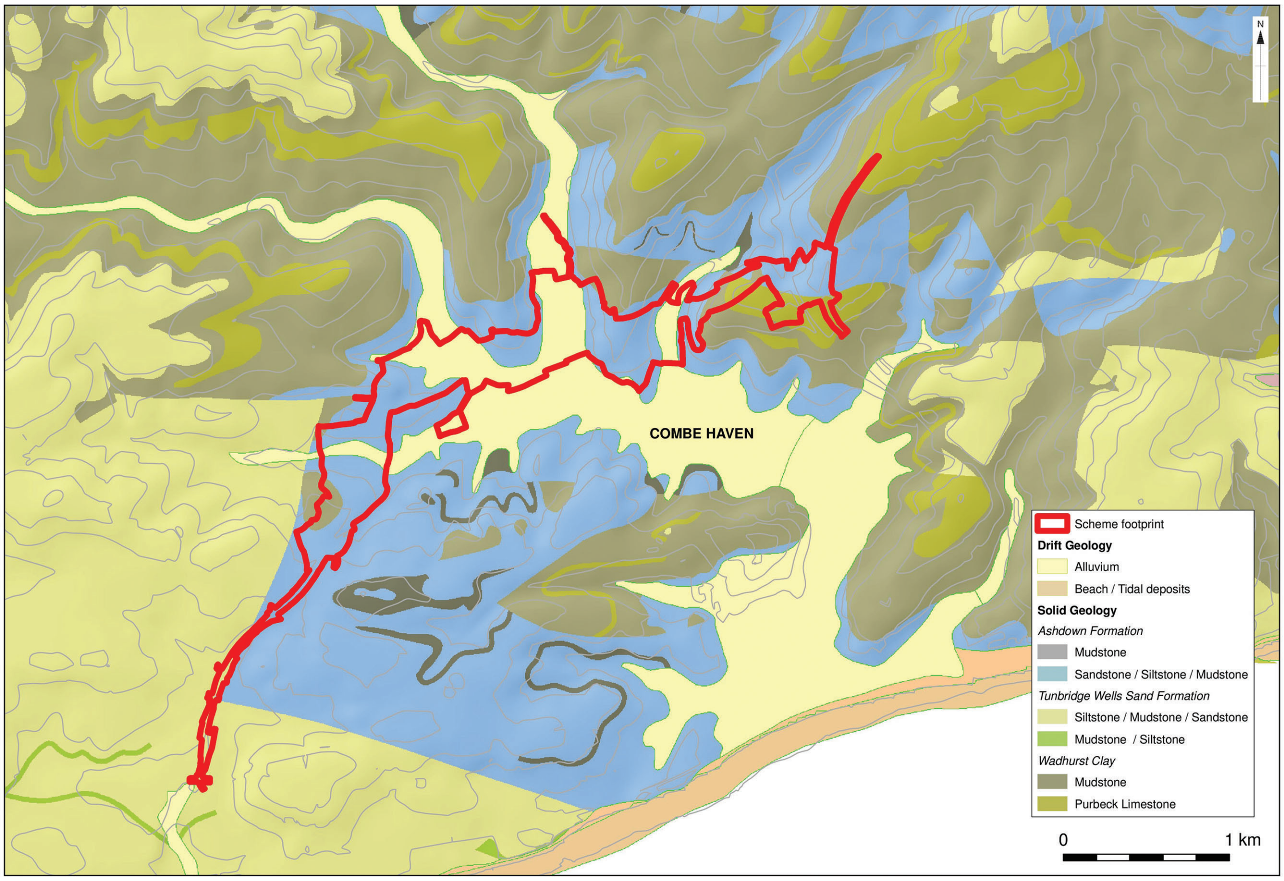


Figure 5.2: Solid and drift geology around the Bexhill to Hastings Link Road

5.3. Methodology

A preliminary deposit model derived from 31 geotechnical boreholes and 63 test pits was developed for the scheme in 2006 as part of the environmental impact assessment by Oxford Archaeology (Champness 2006). This was based partly on a deposit model that had been developed previously for the Combe Haven as part of a research project undertaken by Smyth and Jennings (1988). These studies identified a Holocene alluvial sequence up to 10m deep within the valley floor, including thick organic deposits with the potential to preserve both early prehistoric artefacts and waterlogged cultural and environmental remains. However, the preliminary (2006) model was limited to a linear corridor and to geotechnical sediment descriptions; these highlighted the need to undertake specific geoarchaeological fieldwork investigations and assessment in order to clarify further the potential of the valley sequences and to identify more precisely the archaeological risks to the project.

Consequently, a targeted geoarchaeological field investigation was undertaken in 2007, comprising 9 boreholes and 8 test pits (Figures 5.3 and 5.4). The boreholes were targeted on the deepest sequences in order to recover suitable samples for palaeoenvironmental assessment and radiocarbon dating. The test pits were positioned on the valley edges with the aim of assessing the archaeological potential and preservation of these wetland-dryland interfaces. The remains of a Late Neolithic / Early Bronze Age lithic scatter and burnt mound deposits were identified in the test pits associated with two of the valley edges (Figure 5.5). Evidence for episodes of prehistoric woodland clearance were also detected within the pollen sequence from the Watermill Stream Valley (Champness 2008).

5.4. Deposit interpretations

The fieldwork identified a sequence of laterally equivalent deposits that could be assigned to particular stratigraphic units and that could be correlated along the road corridor with an acceptable level of confidence. These units were correlated in Rockworks14 based on sediment types, elevations and descriptions. Only a broad model was presented during the initial stages of the project, which simplified some of the sedimentary complexity encountered across the valley sequences in order to assist assessment of the archaeological potential of the deposits. This model was updated after the field evaluation following a programme of palaeoenvironmental assessment and radiocarbon dating (Champness 2008). The superficial sediments overlying bedrock comprise units of both

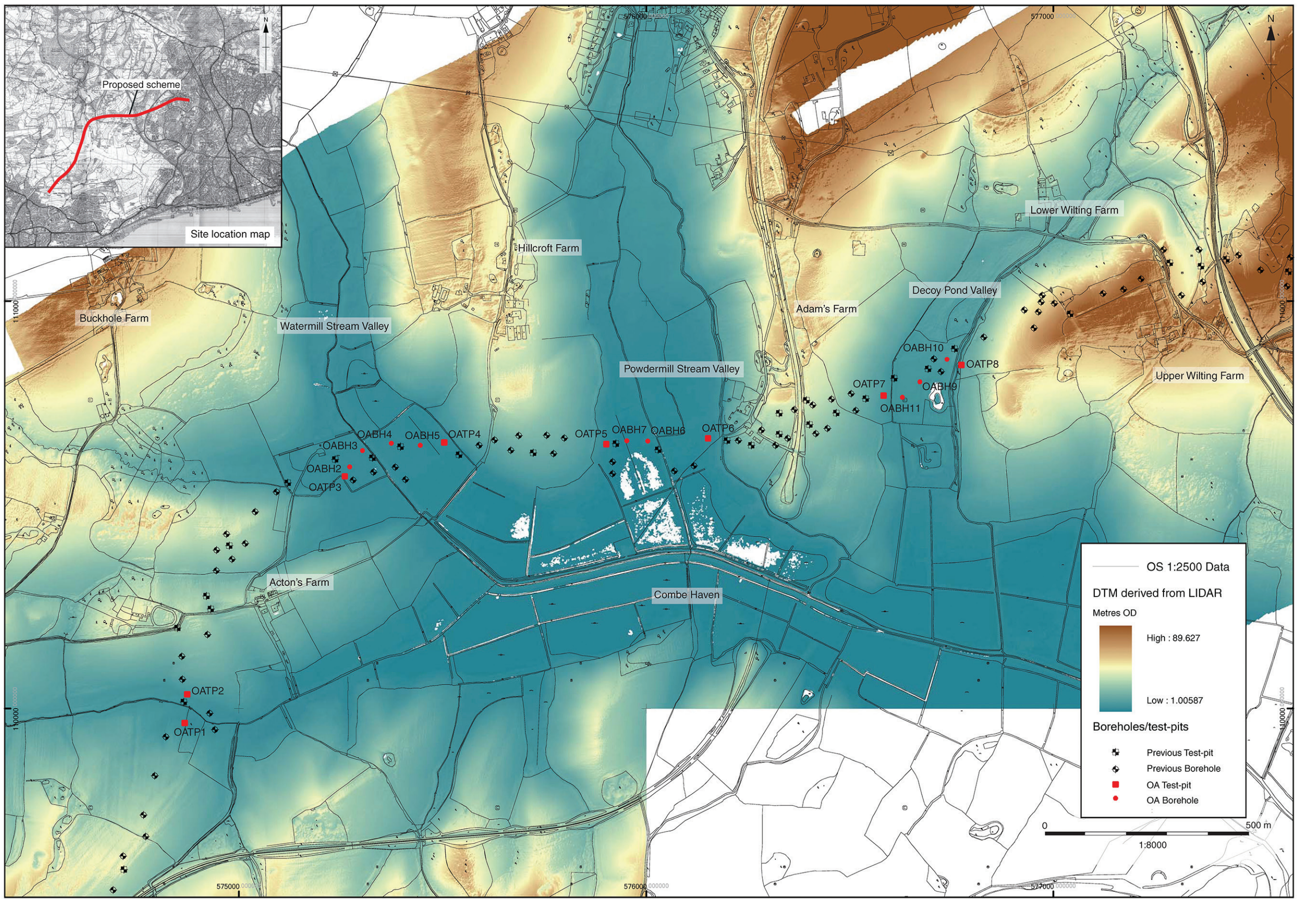


Figure 5.3: Location of geoarchaeological boreholes and test pits along the link road corridor

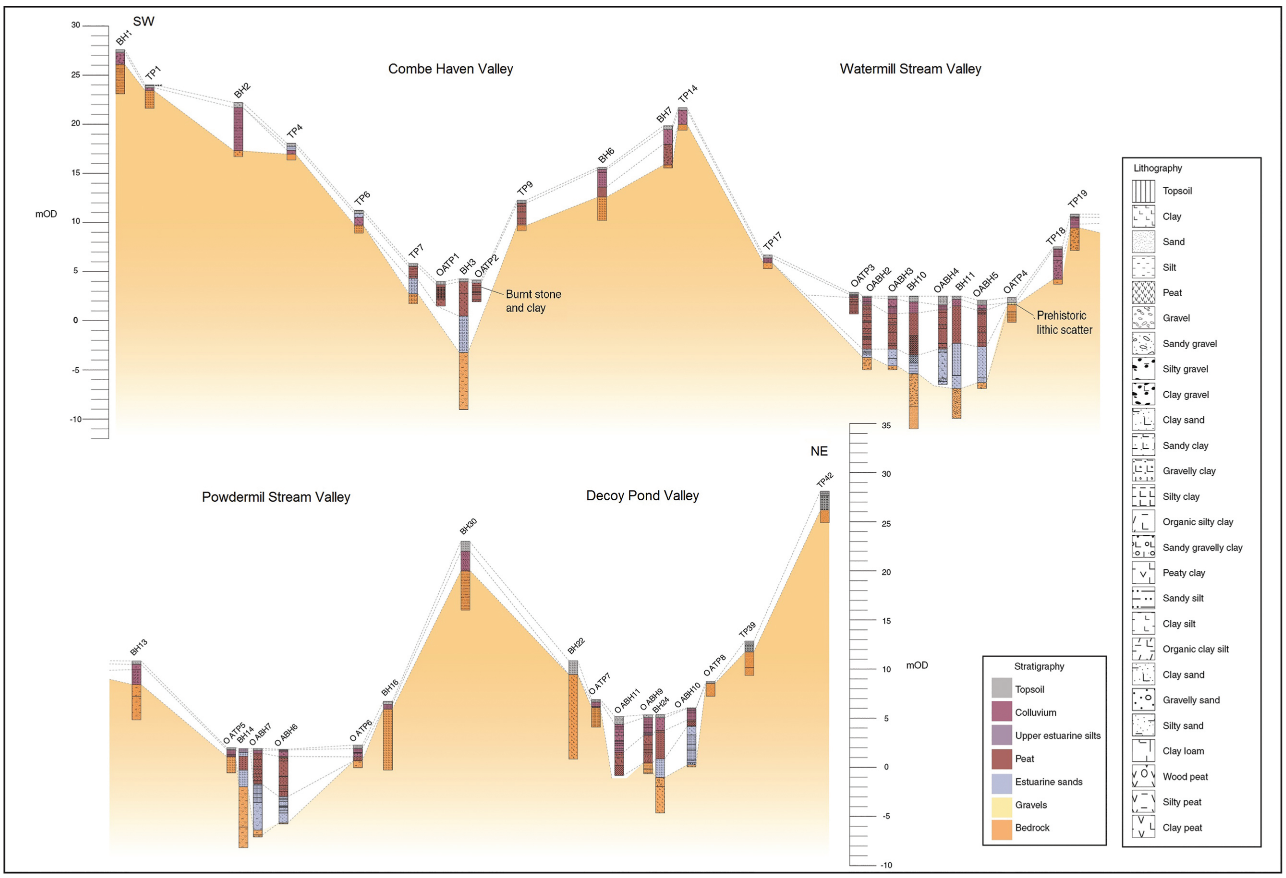


Figure 5.4: Interpretative scheme wide borehole cross-section along the link road corridor

Geoarchaeological Test pit 4, located at the eastern edge of the Watermill Stream, to investigate the archaeological potential and sedimentary sequence of the interface zone.

Ploughsoil	Test pit 4 sedimentary sequence showing the buried prehistoric landsurface, sealed by peat and modern ploughsoil
Peat	Oxidized and dried-out peat deposits
Prehistoric Landsurface Weathered bedrock	Unconformity surface Deflation of the lithic material within the loose sandy sediments up to a depth of 0.60m

Figure 5.5: Stratigraphy of test pit 4 illustrating the identification of a buried early prehistoric land surface

Pleistocene and Holocene age that may be ordered within the sequence that is described below.

5.4.1. Pre-Holocene deposits and topography

Bedrock

The bedrock underlying the Quaternary sediments across the site is mapped as Wadhurst Clays overlying Ashdown Sands, both of Cretaceous age.

Basal gravel (Late Devensian)

The basal unit consists of mixed deposits of fine to coarse weathered bedrock fragments with well-sorted angular to rounded clasts of local sandstone gravel. These deposits are confined to the valley floors and edges, varying in thickness from 1.3m to 5.95m. They accumulated during the last cold stage (the Late Devensian, Marine Isotope Stage 2) and represent material deposited in periglacial river systems during periods of enhanced flow and sedimentation associated with spring and summer snowmelt.

5.4.2. The late Devensian/early Holocene topographic template

The modelled surface of the late Devensian / early Holocene, which lies between *c* -8m and +54m OD, is shown in Figure 5.6. The shape of this surface defines the topography of the early Holocene (post-glacial) landscape along the road scheme. Bates and Bates (2000) refer to this as the 'topographic template' and suggests that variations across it largely dictated patterns of subsequent erosion and sedimentation as rivers and streams established their post-glacial courses.

Examination of this surface reveals a series of ridges and troughs reflecting the forerunners of the four main valleys, with the ground generally rising from west to east. The deep broad troughs of the Watermill and Powdermill streams, extending to depths of 9-10m below ground level (-8m OD), contrast strongly with the shallower and more confined valleys of the Combe Haven and Decoy Pond streams. The surface plot also reveals the irregular nature of the valley edges, with evidence of natural buried valley spurs and peninsulas which may have acted as foci for human activity in the past.

5.4.3. Holocene sedimentation

Early Holocene land surface

A remnant of the pre-inundation early Holocene land surface, which would have been characterised by woodland, was found preserved within BH49 and BH51 at a depth of between 8m and 9.25m (-4.9m and -7.64m OD) in the Powdermill stream valley. These deposits contained frequent wood and plant remains, including notable

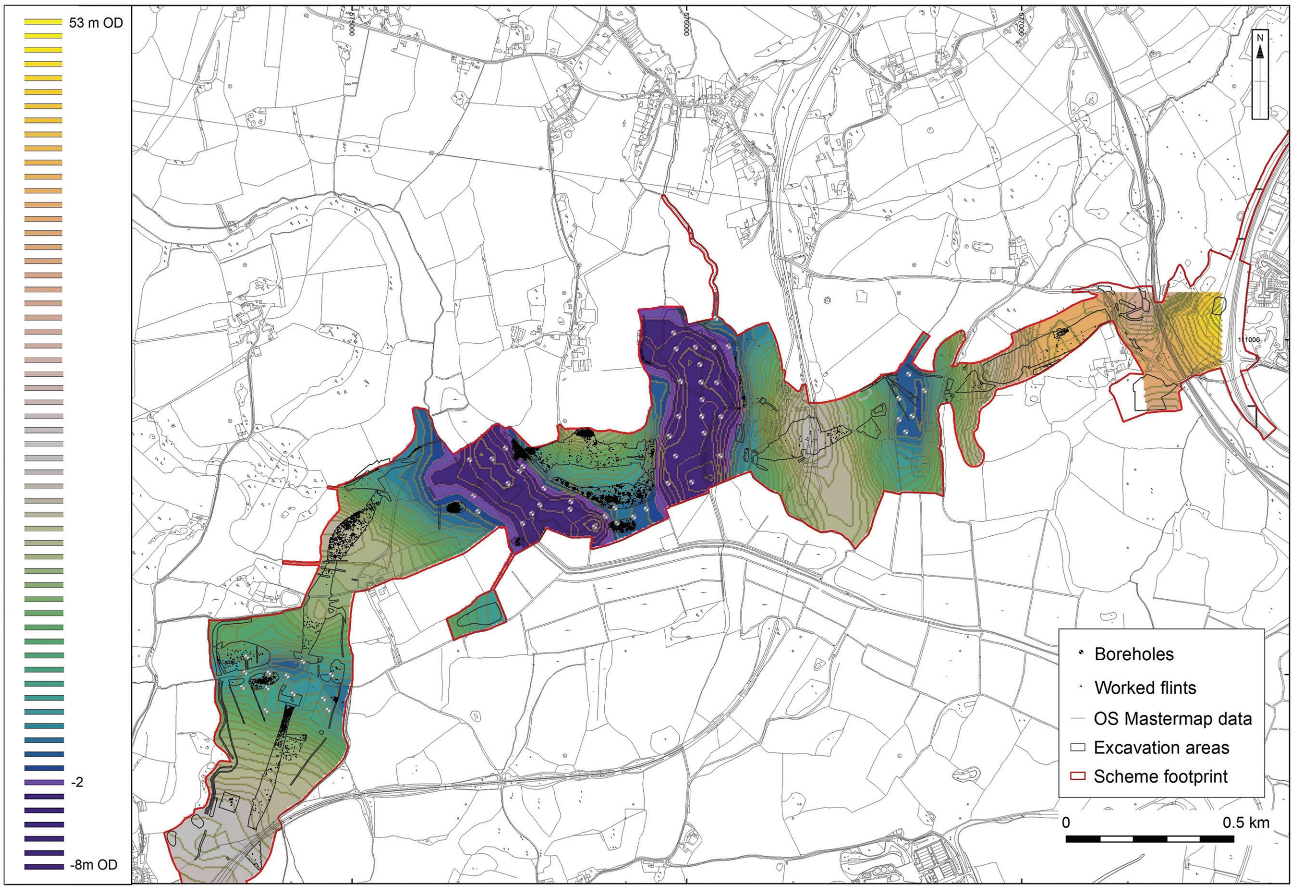


Figure 5.6: Modelled landsurface of the early Holocene template along the link road corridor based on borehole and test pit data

quantities of hazelnuts; radiocarbon dating provided an age estimate of *c* 8,000 BC. The deposits were recorded overlying the basal gravels at various elevations and were sealed by the estuarine alluvium.

Estuarine alluvium

These deposits consist of pale grey, fine-grained silts and sands with interbedded, laminated clays; they occupy the valley floors between -7m OD and 0m OD and are usually gleyed. They are interpreted as representing a rapid phase of post-glacial sea-level rise and marine transgression, when the Combe Haven and surrounding valleys would have developed into tidal inlets and salt-marsh.

Combe Haven peat sequence

During the mid-Holocene, there was a major reduction in the rate of sea-level rise. A sequence of freshwater peats started to accumulate as the marine influence in the Combe Haven valley decreased and the inlet was cut off from tidal processes. The main period of regression was characterised by the accumulation of peats and other organic deposits indicative of a mosaic of different wetland environments. The peat accumulated between -1m OD and +2m OD and was up to 4m thick. The formation of these deposits has been radiocarbon-dated to between 4450-4330 cal BC (SUERC-17363) and 1890-1690 cal BC (SUERC-17364). Detailed examination of the sequence revealed significant complexity within the main sequence, indicated by at least two phases of peat formation interspersed with periods of minerogenic sedimentation, reflecting freshwater (river) flooding, shifting wetland environments and enhanced channel activity.

Upper estuarine alluvium

The upper silts mark a shift away from the freshwater deposition of organic sediments to minerogenic silty clays, representing salt-marsh environments and a return to marine conditions. These deposits consist of light-grey/greyish-brown sandy clays and silty clays, occasionally with peat lenses near to the base. The estuarine alluvium ranges in thickness from 0.4m to 1.6m and was located at approximately +1m OD to +3m OD.

Colluvial deposits

Sandy deposits comprising a mixture of weathered bedrock and other local material derived from immediately upslope were interpreted as colluvium, and were recorded along the valley margins and floors. They reflect erosion and deposition associated with forest clearance and agricultural activity.

Topsoil and ploughsoil

These deposits consist of a mixture of firm, brown, sandy clay and clay derived from a variety of underlying parent materials. They include ploughsoils and thin marshy topsoils.

5.5. Redefining the deposit model: further fieldwork investigations

Further widespread investigation of the valley floors was recommended, and was undertaken by means of an electric conductivity survey (Champness and Bates 2008) using an EM31 ground conductivity meter to map the different sedimentary zones and their interfaces (Table 5.1). The survey identified areas of high ground and submerged islands away from the main route with enhanced potential for the preservation of archaeological remains. This data was used to create a landscape zonation model for the valley floors that was used to develop a trenching strategy (Figure 5.7).

Field evaluation across the scheme was undertaken in 2013, and comprised 58 boreholes drilled with a terrier rig, followed by 181 trial trenches and 24 geoarchaeological test pits (Figure 5.8). The fieldwork was undertaken collaboratively by geoarchaeologists and archaeologists. Many of the trenches were targeted on the valley edges that were determined by landscape modelling. The boreholes were focused on the valley floors in order to recover samples for dating and palaeoenvironmental assessment. The deposit model was updated using the new dataset, including biostratigraphic and dating information derived from the analysis of borehole samples.

The results of the borehole evaluation survey were used to update the deposit model that had been devised on the basis of previous field investigations (Champness 2006; 2008; 2009; Champness and Bates 2008; Champness and Hughes 2012). The stratigraphic correlations were revisited in the light of the more detailed geoarchaeological recording and the better spatial coverage of the valley sequences obtained from the borehole survey. In addition, the valley cross-sections were updated with more detailed lithological information in order to illustrate the complexity of the sediment sequences and landform features that existed along the scheme.

The evaluation provided an opportunity to test the deposit model and to search for further evidence of early prehistoric activity. The evaluation recovered 205 lithic artefacts, the spatial distribution of which indicated a total of 11 potential scatters. It is noteworthy that significantly more lithic artefacts (120 pieces) were identified in the test pits and boreholes that penetrated through the bedrock deposits than were recovered from the evaluation trenches that only went to surface of the bedrock. The model suggested that these artefacts were embedded to a depth of up 0.60m, below the level of the weathered bedrock surface (Figures 5.5 and 5.9). A combined approach, using trenching, boreholes and deep test pitting to excavate into the weathered bedrock surface was therefore necessary in order to establish the true potential of these deposits to contain early prehistoric lithic scatters. Consequently, the evaluation was found to have significantly underestimated the potential number of lithic scatters identified during the subsequent excavations.

Table 5.1: Summary of landscape zonation model

Landscape zones	**Litho-stratigraphic units**	**Indicative depth (below ground level (bgl)**	**Sedimentary sequence**	**Palaeoenvironment**	**Archaeological potential**
Zone 1 Inter-tidal sediments	Upper estuarine sands	0.4m-1.6m bgl	Deeply buried alluvial and estuarine sequences overlying a pre-inundation land surface, sandy gravel and bedrock	Salt-marsh conditions developing over an early land surface, freshwater carr and reedswamp, followed by a return to salt-marsh conditions	Waterlogged remains including prehistoric trackways and wooden platforms. Votive offerings
	Combe Haven Peats	1m-6m bgl			
	Estuarine silts and sands	5m-9m bgl			
	Early Holocene land surface	8m-9.25m bgl			
	Sandy gravels	8m-10m bgl			
	Bedrock	6m-10m bgl			
Zone 2 Interface zones	Upper estuarine sands	0.4m-1.2m bgl	Shallow weathered bedrock underlying thin peat and estuarine deposits	Edge environments at the interface between wetland and dryland zones	Prehistoric lithic scatters and burnt mound deposits
	Peats	0.60m-2m bgl			
	Buried land surface	0.60m-2m bgl			
	Bedrock	0.60m-2m bgl			
Zone 3 Valley slopes and ridges	Colluvium	0.40m-1.5m bgl	Shallow bedrock deposits overlying thick colluvial deposits	Buried soils, wooded and partially cleared landscapes	Bronze Age round barrows, field systems and Roman iron working sites
	Bedrock	0.40m-1.5m bgl			
Zone 4 Valley floor islands	Upper estuarine sands	0.40m-0.60m bgl	Shallow bedrock underlying thin peat and estuarine deposits	Prehistoric land surfaces overlain by waterlogged carr deposits and salt-marsh	Prehistoric lithic scatters and burnt mound deposits
	Peats	0.50m-1m bgl			
	Buried land surface	0.40m-0.80m bgl			
	Bedrock	0.60m-1m bgl			
Zone 5 Bedrock variations	Bedrock	0.40m-1.2m bgl	Shallow bedrock with alluvial clays	Non-waterlogged drainage channel environments	Prehistoric burnt mounds and Roman iron working

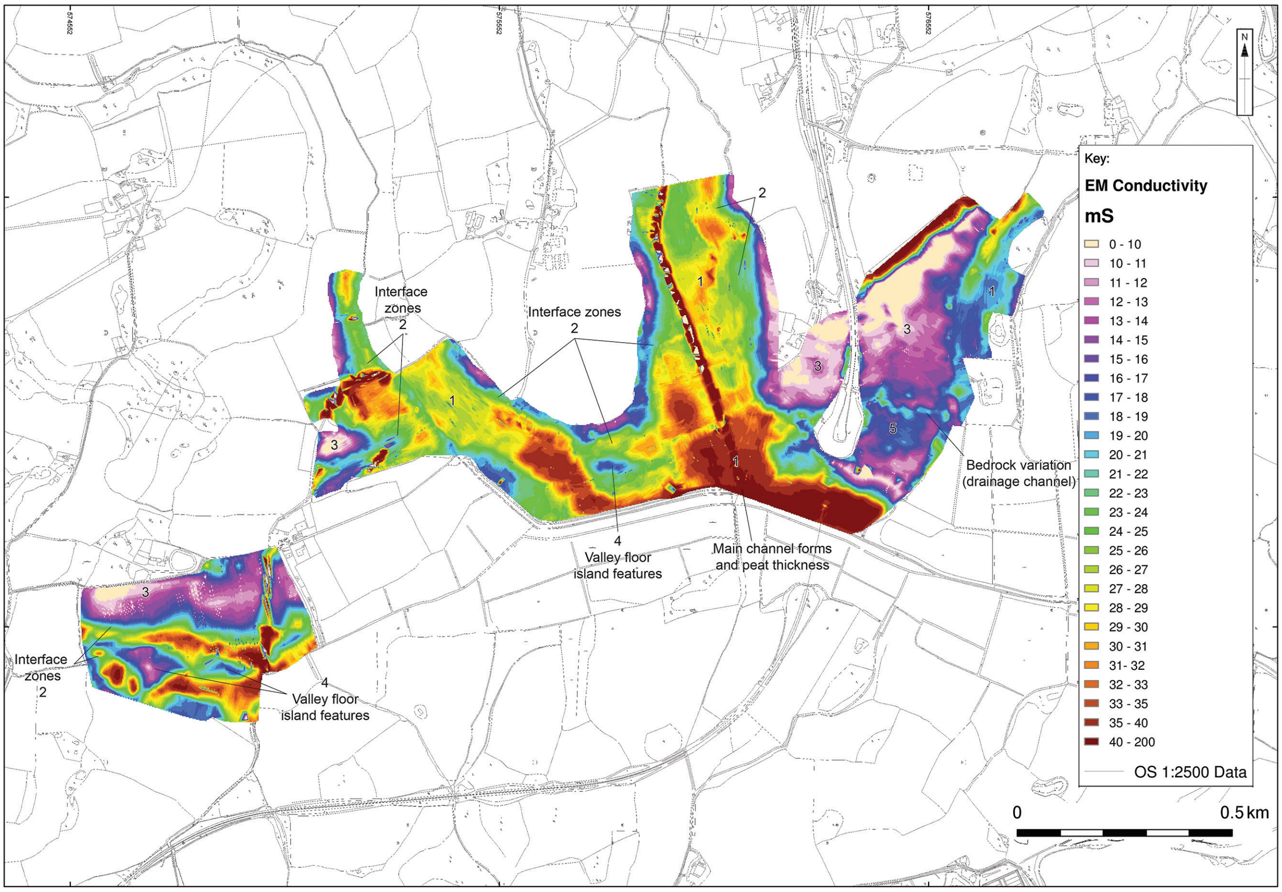


Figure 5.7: Results of the conductivity survey and landscape zones along the link road corridor

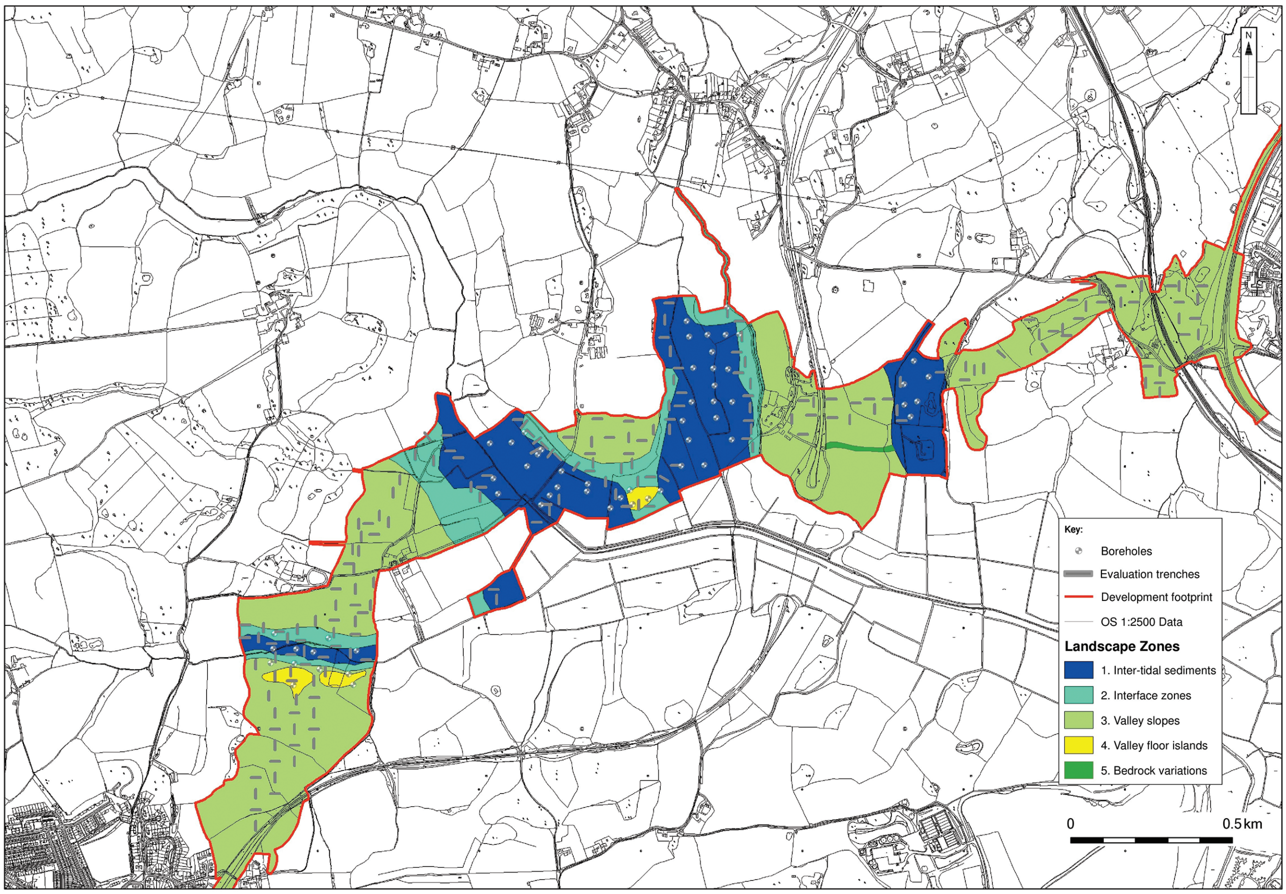
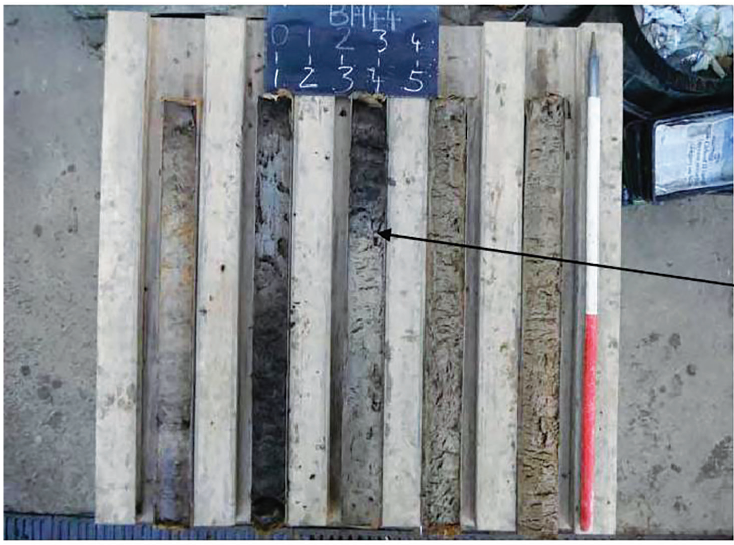


Figure 5.8: The location of evaluation boreholes, test pits and trenches, set out on the basis of geoarchaeological analysis of the link road corridor

Stepped evaluation trenches targeted on the wetland interface zones along the Powdermill Stream



Borehole sample OABH44 taken at the edge of the Powdermill Stream showing a sequence of upper estuarine silts and peat overlying a buried prehistoric landsurface

Worked flint

Worked wood identified within the upper peat surface at the western edge of the Watermill Stream associated with a potential lithic scatter

Figure 5.9: Plates illustrating the identification of early prehistoric remains along the link road corridor

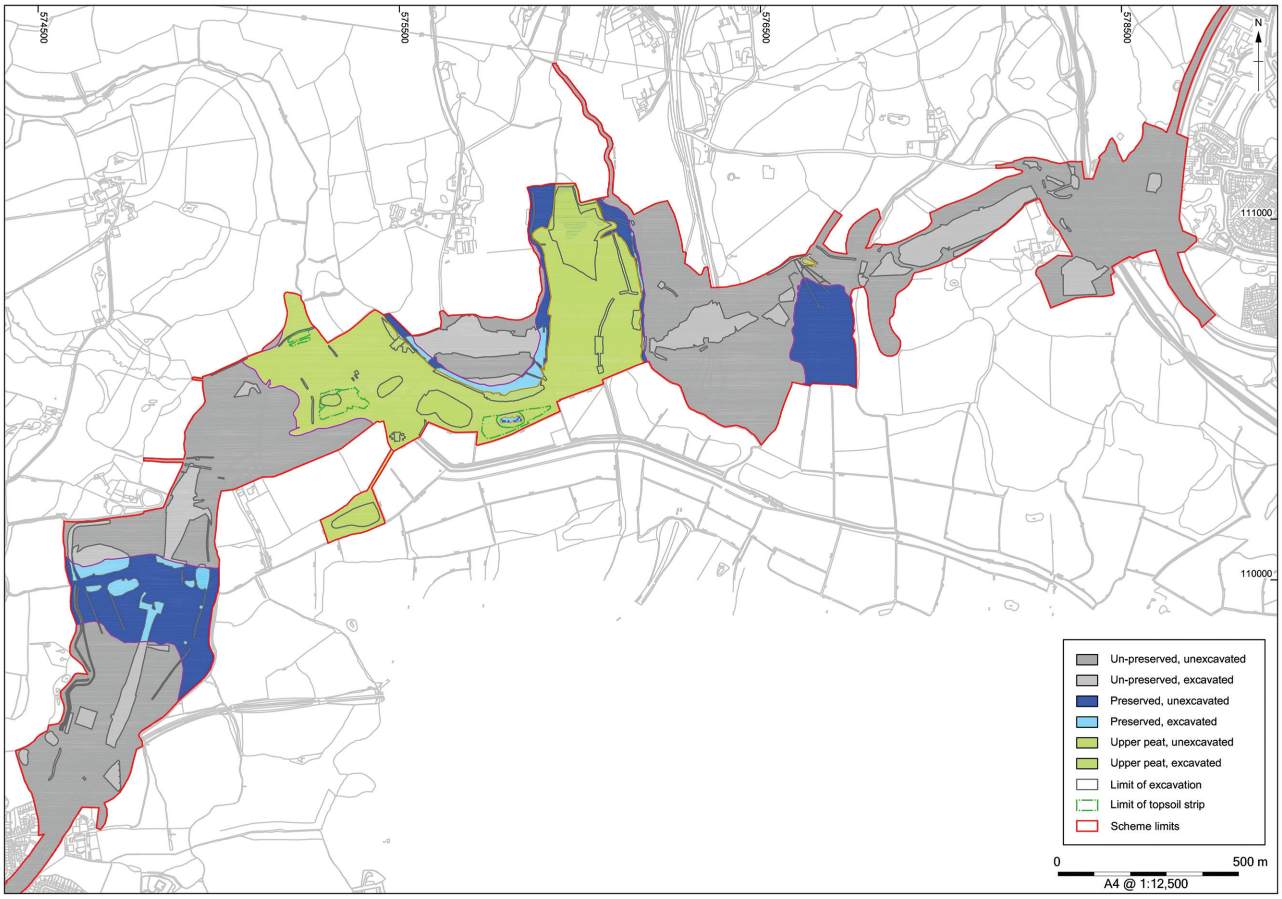


Figure 5.10: Zonation of the link road corridor based on geoarchaeological evidence and development of mitigation areas

The results of the evaluation were used to develop a mitigation strategy, targeting areas within the model that had yielded lithic artefacts or were highlighted as having enhanced archaeological potential. Where possible, the scheme design was modified in order to help preserve archaeological sites *in situ*; where this was not possible, sites of potential archaeological interest were targeted for excavation (Figure 5.10). A major excavation was undertaken between 2012-2014. Evidence of early prehistoric activity was identified in the form of over 200 individual lithic artefact scatters and nearly half a million worked flints. This activity was concentrated mainly along the edges of the Combe Haven, Watermill and Powdermill valley sequences.

5.6. Conclusions: benefits of deposit modelling and opportunities for further work

The Bexhill to Hastings deposit model developed through the life of the project. It provided a valuable framework in which to approach and understand a complex buried landscape in order to develop suitable archaeological investigation techniques and mitigation strategies. It also provided an interpretative framework for all stakeholders in the project, and facilitated in turn better communication between project partners.

The model initially provided a valuable predictive tool that helped to establish the archaeological potential of the valley sequences, identifying areas and horizons for further investigation. During the evaluation stages it developed into a mitigation tool, identifying areas of archaeological potential that warranted further investigation through excavation, watching brief or preservation *in situ*. Following the excavation and post-excavation phases, the model was used as an interpretative tool, helping to explain the location and density of prehistoric activity across the defined landscape zones.

The benefit of the model is that it allowed for a closely targeted and cost-effective approach to investigating the valley floor sequences. Without the deposit model and geoarchaeological input throughout the archaeological process, the sampling of the valley floor deposits would have been less focused and arguably less productive.

The limitation of the approach is that some of the techniques and approaches applied here are more feasible on large-scale, better resourced and long-term infrastructure projects and would be less suitable for some shorter or smaller-scale schemes. The model developed in stages and required significant involvement of geoarchaeological and environmental specialists in the fieldwork alongside archaeologists. The project would have benefited from more time spent in communicating and training of the field teams tasked with investigating in more traditional ways the preserved archaeological remains. Where opportunities were missed during the evaluation, it was when the field teams were not fully briefed on the deposit model and about the potential precise location of lithic artefacts (for example, in the upper parts of the weathered bedrock surface).

The model ultimately contributed to the identification and investigation of a nationally important early prehistoric landscape around the Combe Haven. Principally, this has highlighted the need for further comparative geoarchaeological and palaeoenvironmental investigations of other valley floor sequences at the wetland-dryland interface within East Sussex. The final deposit model will be developed further as part of the post-excavation analysis and will eventually be incorporated within the project publication. The model will be archived as both a GIS project and as shape files and the Rockworks database will be deposited with the Archaeology Data Service.

Acknowledgements

Oxford Archaeology would like to thank East Sussex County Council (ESCC) and the various contractors who commissioned these investigations. Particular thanks are due to Casper Johnson (County Archaeologist) for all his help and advice during the project, Greg Chuter (Assistant County Archaeologist) and Sophie Unger (ESCC HER officer) for providing the necessary HER data and information.

In the course of the project research information and advice was provided by Dr Martin Bates, University of Wales, Lampeter, and Jane Corcoran, Science Advisor, for Historic England. The environmental and geoarchaeological work was coordinated by Rebecca Nicholson and Elizabeth Stafford respectively. The GIS project was designed and collated by Gary Jones and Matt Bradley.

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Constructing a geoarchaeological deposit model: Bexhill to Hastings

↓

Assess pre-existing data

- Boreholes (n=31) and test pits (n=63) undertaken as part of an Environment Impact Assessment in 2006
- Boreholes used to construct a deposit model developed for a research project in the 1980s

↓

Develop rationale for model construction and key aims and objectives

- Identify buried topographic features that were the focus of prehistoric activity
- To inform archaeological risk and inform development of evaluation and mitigation strategies

↓

Commission further ground investigations, including:

- Further purposive boreholes (n=9) and test pits (n=-8) undertaken in 2007 to recover samples for palaeoenvironmental analysis and radiocarbon dating

↓

Can the deposit model be constructed using pre-existing data?

Yes, but its reliability increased by the capture of new data

↓

Construct deposit model comprising of:

- Key early Holocene palaeolandsurface
- Stratigraphic cross-sections along the entire route
- Key landscape zones for archaeological evaluation and mitigation

↓

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- Evaluation and mitigation process allowed continual testing of deposit model and adaption of strategy during fieldwork (if needed). As well as helping to target discreet sites (e.g. lithic scatters), the model was important in identifying areas where preservation *in situ* was appropriate

↓

Revise final product

Model used during on-going post-excavation process and will continue to be consulted when moving forward towards publication of the project

↓

Archive and reuse

Model will be archived as both a GIS project, as shapefiles and a Rockworks database. It will be deposited with the Archaeological Data Service

SECTION 4

Modelling where dryland meets wetland

6. Grove Farm, Nottingham: modelling the alluvial sequence of the Middle Trent Valley

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Abstract

A proposed wind turbine development on the floodplain of the River Trent on the western outskirts of Nottingham required the construction of a deposit model prior to further archaeological evaluation and the development of an appropriate mitigation strategy. A series of 54 purposive boreholes was drilled and recorded with the aim of creating a deposit model that would guide future archaeological investigations. Another 6 boreholes and 19 test pits were subsequently excavated for geotechnical ground investigations, permitting refinement of the initial deposit model. These surveys permitted identification of several macro-stratigraphic units across the development area, allowing archaeological potential to be defined through geomorphological zonation of the site; landform elements included one or more palaeochannels, a river terrace and an alluvial floodplain, with the Holocene sequences extending from between *c* 0.4 and 7m below the modern ground level (BGL). A subsequent gradiometer survey refined the zonation of the site and allowed the identification of archaeological features cut into river terraces and the upper deposits of the deep Holocene alluvial sequence. No further archaeological works were conducted after the gradiometer survey which, together with the preceding ground investigations, provided sufficient evidence for the developer, consultant and archaeological curators to determine the potential archaeological impact of the proposed construction work and the likely scale of further evaluation and mitigation work. In this respect, the project provides a model for best practice in alluvial environments impacted by construction activity.

6.1. Introduction

We focus in this paper upon a deposit model that was constructed in advance of the development by the University of Nottingham of three wind turbines on sports fields and farmland spanning the boundary between Nottingham City and Nottinghamshire (NGR: 455200 336300; Figure 6.1). The development would have involved disturbance of the contemporary floodplain of the River Trent and adjacent river terrace deposits, with unknown impacts upon subsurface deposits, leading the City and County archaeological curators to request a desk-based assessment and preliminary ground investigations prior to the granting of planning permission. The work was undertaken by Trent & Peak Archaeology and the University of Brighton, following a desk-based assessment by AECOM Ltd, with AECOM performing a consultancy role on behalf of the developer.

The initial brief from the consultant requested a gradiometer survey of the entire development area. However, given the potential depths of the alluvial sequences in the middle reaches of the Trent Valley (Bridgland *et al* 2014; Knight and Howard 2004), it was recommended that targeted ground investigations should be conducted initially to clarify the subsurface stratigraphy and to assess the potential value of gradiometry as a prospection technique. The consultant was happy to revise the initial brief, and it was agreed to combine a purposive borehole survey with the geotechnical investigations accompanying development in order to establish a deposit model that would inform future archaeological investigations.

6.2. Aims and objectives

The British Geological Survey (BGS) had previously mapped the area as containing ‘Undifferentiated Alluvium’: a BGS classification that can encompass material from a host of different depositional environments. The deposit model was constructed at the assessment stage in order to enhance our understanding of the subsurface sediment stratigraphy, establish the site’s

Comparative data table for this deposit model	
Deposit model location	Grove Farm, Nottingham, UK (NGR: 455200 336300)
Depositional environment	Floodplain sequence of the River Trent
Size of deposit model	The deposit model extended across an area of *c* 21 ha
Data collection strategies	Borehole surveys and geotechnical test pits, followed by extensive gradiometer survey
Position in the archaeological process	Initial ground investigations, guided by the results of desk-based assessment. Following construction of the deposit model, the developer decided not to proceed with construction work
Reason for deposit model construction	To model the interfaces between the key stratigraphic units, characterise the recorded Pleistocene and Holocene sediments, establish the potential for preserved archaeological and environmental remains, and establish a methodology for further evaluation and mitigation work
Archaeological questions	Define the depth of the Holocene sediment sequences and the likely locations of archaeological remains within these sequences
Software and modelling process	The data were sorted in Excel, with the surfaces of the key stratigraphic sediment units modelled in ArcGIS. A representative section was drawn in Illustrator. Gradiometer data were processed in ArcheoSurveyor software and were imported into ArcGIS
Outputs from the deposit model	A series of topographically modelled surfaces and representative cross sections; gradiometer map, showing geomorphological and archaeological features; and zonation of the site into different geomorphological depositional environments, with a statement of their archaeological potential

archaeological and environmental potential, and facilitate the development of future programmes of evaluation. The process of deposit modelling was complicated by the location of much of the development area on sports fields; these had previously been ploughed and rolled flat, thereby removing any topographic expression of surface landforms such as palaeochannels. An examinations of air photographs and plots derived from airborne lidar surveys also failed to reveal traces of buried landforms. Particular focus was placed, therefore, upon the location by ground investigations of channel deposits which might elucidate development of the riverine environment and preserve organic remains with potential for dating the channels and elucidating changes in vegetation and land-use.

6.3. Fieldwork methodology

Three stages of fieldwork were carried out with the aim of developing a robust deposit model that could provide a valuable framework for further evaluation and mitigation work.

Stage 1: geoarchaeological borehole survey
54 purposive boreholes were drilled using a rotary corer on a regular grid (50m intervals; Figure 6.2). Site Investigation Services Ltd was contracted to undertake the boreholes under the supervision of one of the authors (CC). Detailed notes were compiled for each borehole of sediment types, depths and interfaces. The presence of a geoarchaeologist was essential for data capture at a resolution suitable for deposit modelling and archaeological investigations.

Stage 2: geotechnical investigations
The locations of each of the proposed wind turbines were investigated by Castle Roc Geotech. Six cable percussion boreholes were drilled to depths of *c* 8m below modern ground level (BGL) and 19 geotechnical test pits were dug by a JCB mechanical excavator equipped with a toothless bucket (Figure 6.2). This Stage 2 fieldwork was undertaken several months after completing the original deposit model, requiring it to be updated. All of these geotechnical interventions were monitored by one of the authors (CC); data were collected using the same

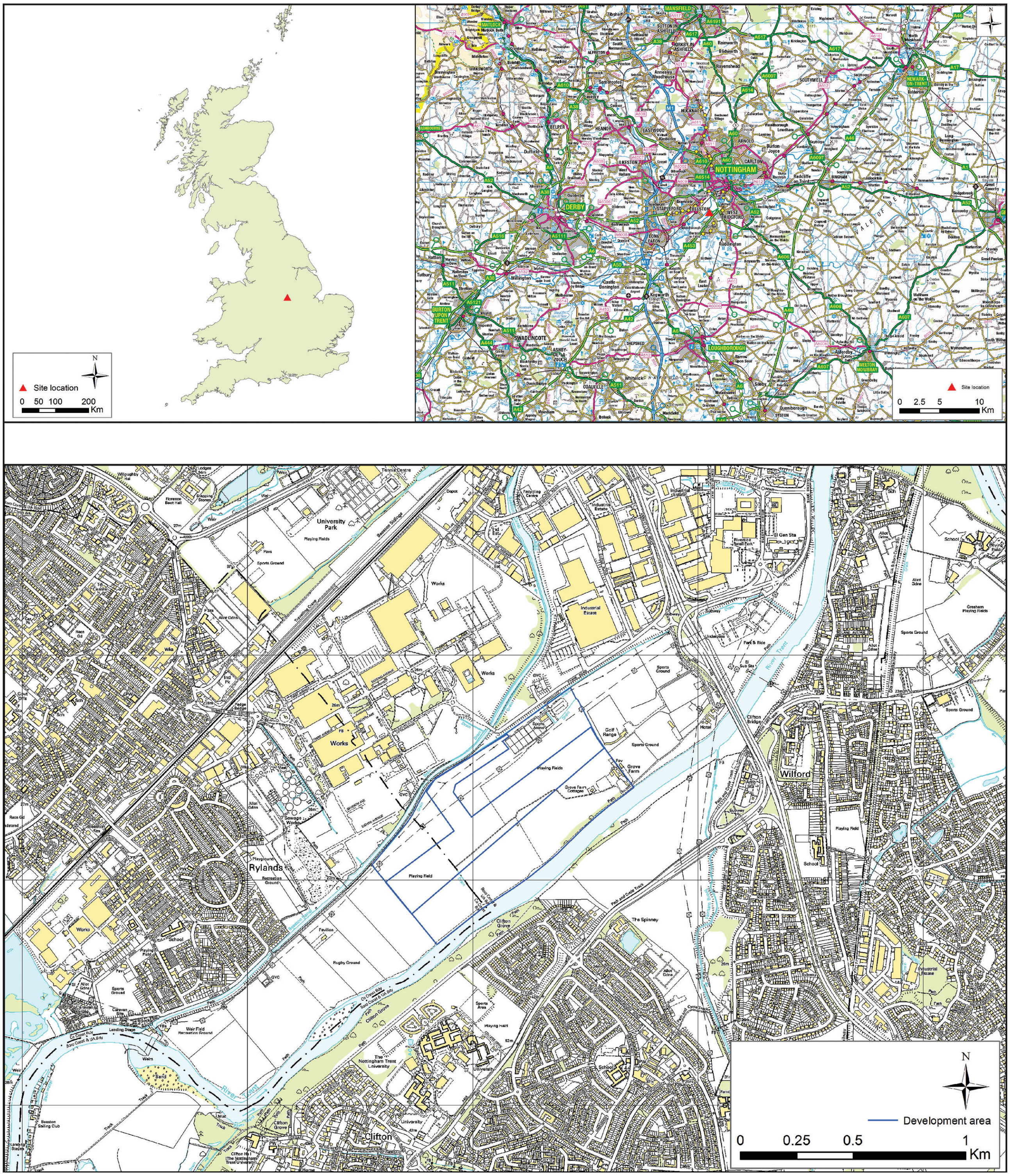

Figure 6.1: Location of the development area on the Trent floodplain (NGR:455200 336300 HMSO Crown Copyright, OS licence no. 100019139)

recording system that was employed during Stage 1, ensuring continuity and comparability of data.

Stage 3: gradiometer survey
Completion of the Stage 1 and 2 intrusive investigations provided the foundation for a deposit model that was refined by a gradiometer survey aimed at clarifying the subsurface topography deduced from borehole analysis and investigating whether features of archaeological interest might survive in areas not sealed by significant depths of sediment. Details of the methodology are provided in Chapter 6.5, where the results are discussed

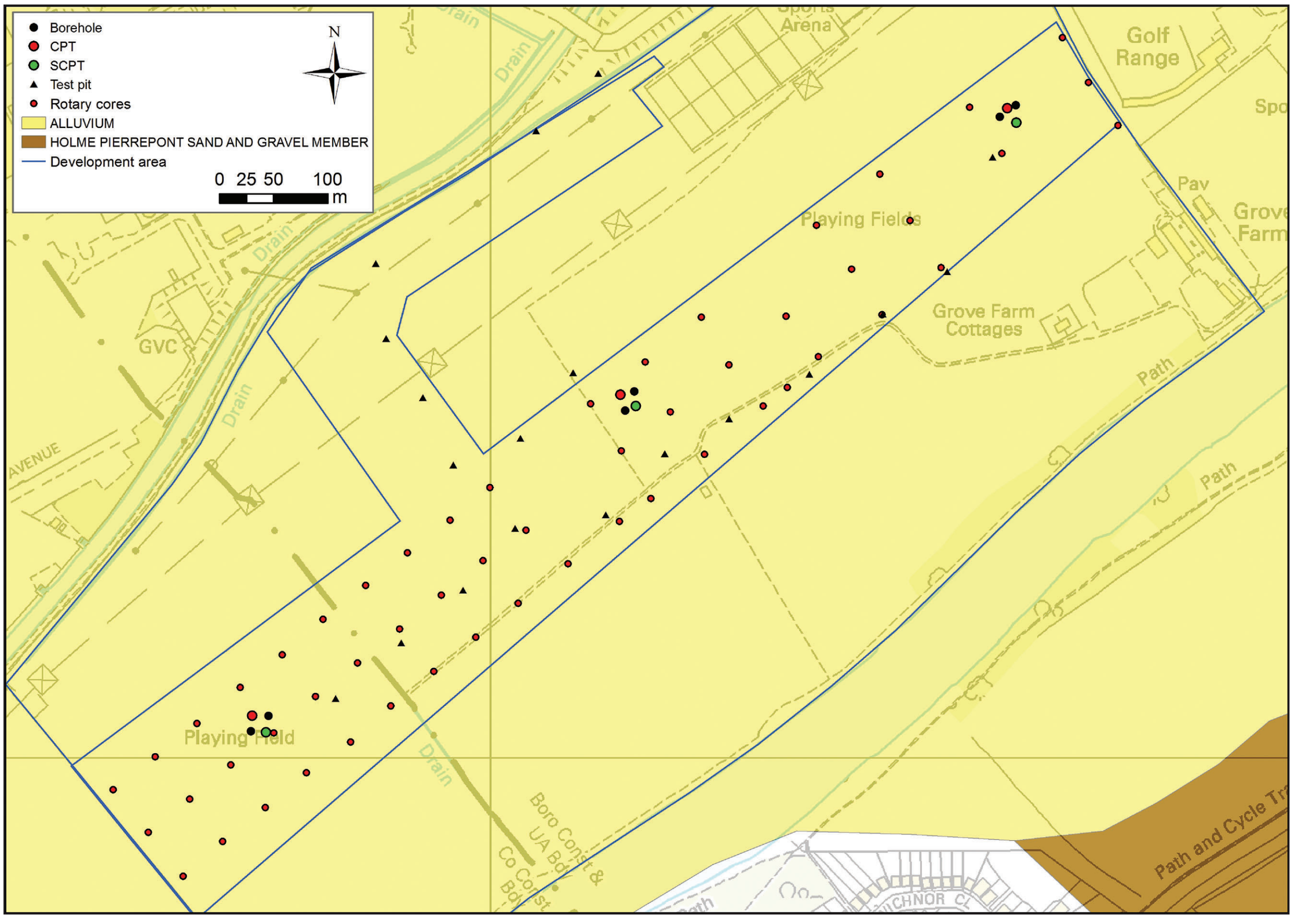

Figure 6.2: Location of the Stage 1 rotary cores, cable percussion boreholes (BH), cone penetration tests (CPT), seismic cone penetration tests (SCPT) and test-pits (TP; HMSO Crown Copyright, OS licence no. 100019139)

with reference to the geomorphic zones that were identified by analysis of the borehole data acquired during Stages 1 and 2.

6.4. Analysis of Stage 1 and Stage 2 borehole data

The borehole data obtained during Stages 1 and 2 were grouped into stratigraphic units using Excel software. Two key measurements were selected for each unit: its thickness and the depth of its upper surface below modern ground level (BGL). These data were exported into ArcGIS and modelled via a kriging function to allow a 2-dimensional reconstruction of the subsurface stratigraphy and a pseudo-3-dimensional display within ArcScene.

6.4.1. Key stratigraphic units

Five key stratigraphic units were revealed during ground investigations and are described briefly below, broadly in reverse order of date of formation.

- *Minerogenic alluvium* (Figures 6.3a&b)
  This sediment unit comprised mainly a light brown silty clay, with iron (Fe) and manganese (Mn) mottling, and formed the uppermost unit in the sediment sequence (Figure 8b). It was recorded throughout the development area, and represents the upper oxidised zone of the alluvial sequence. This unit varied significantly in depth across the application area, with a thin covering towards the west and much thicker deposits towards the east. It extended to a depth of only *c.* 0.4m BGL at the highest point of the river terrace sands and gravels that extended across the western part of the study area (Chapter 6.4.2: Zone 1), explaining the visibility of cropmarks and the presence of well-defined gradiometer anomalies of archaeological interest on this higher terrace landform. Towards the east of the development area it was stratified above orange-grey or orange-brown clayey sands and a dark grey sandy clay that might also be of alluvial origin (Figure 8b: deposits 12–14) but further work would be required to establish with greater confidence the origin of these lower deposits.

- *Organic-rich palaeochannel sediments* (Figure 6.4a)
  This sediment unit was characterised by brown to blue-grey silty clays, peaty clays and blue-grey clayey sands, and incorporated several layers with moderate to good preservation of organic matter.

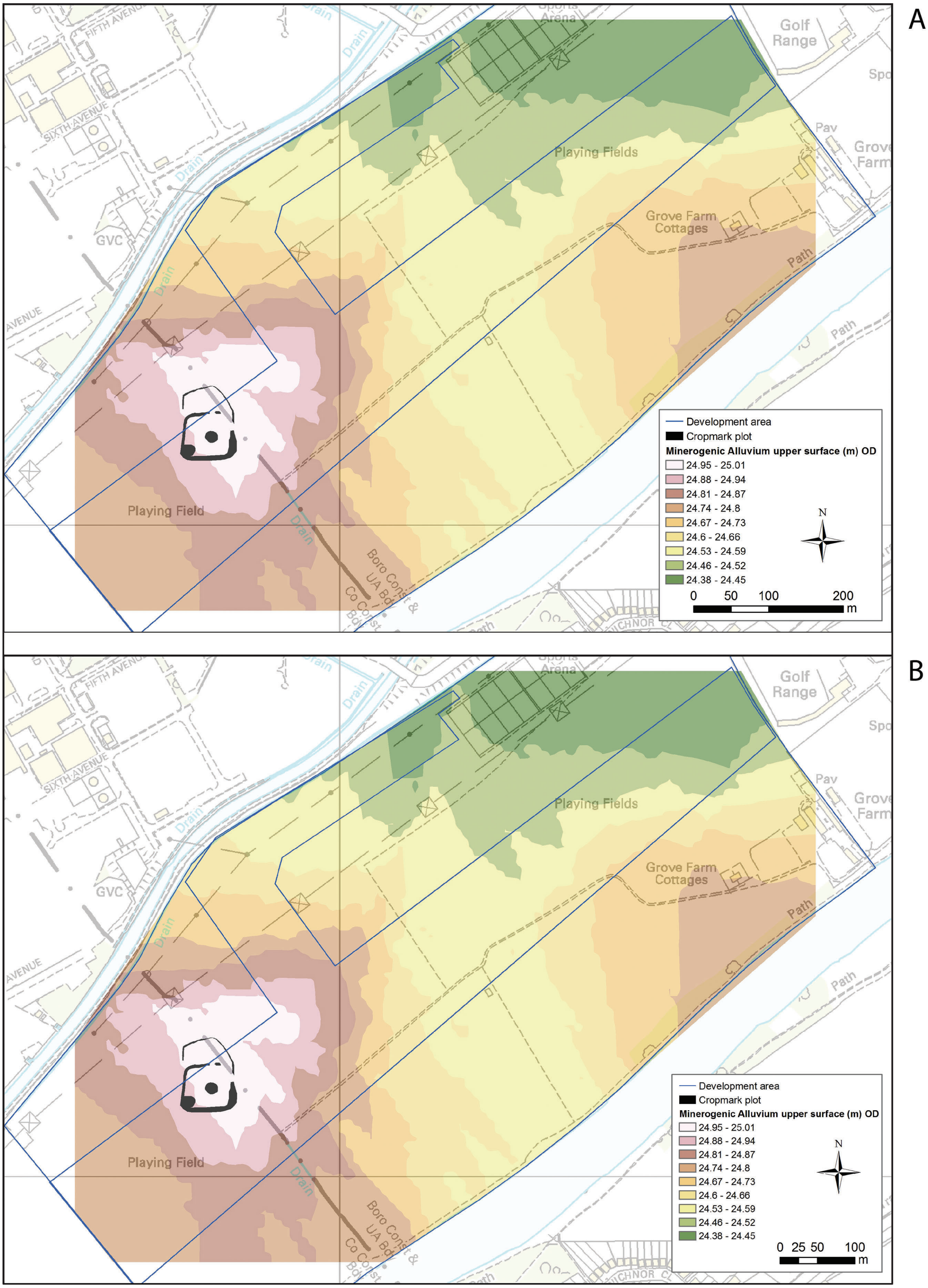

Figure 6.3: The modelled upper surface (A) and thickness (B) of the Minerogenic Alluvium (HMSO Crown Copyright, OS licence no. 100019139)

A

B

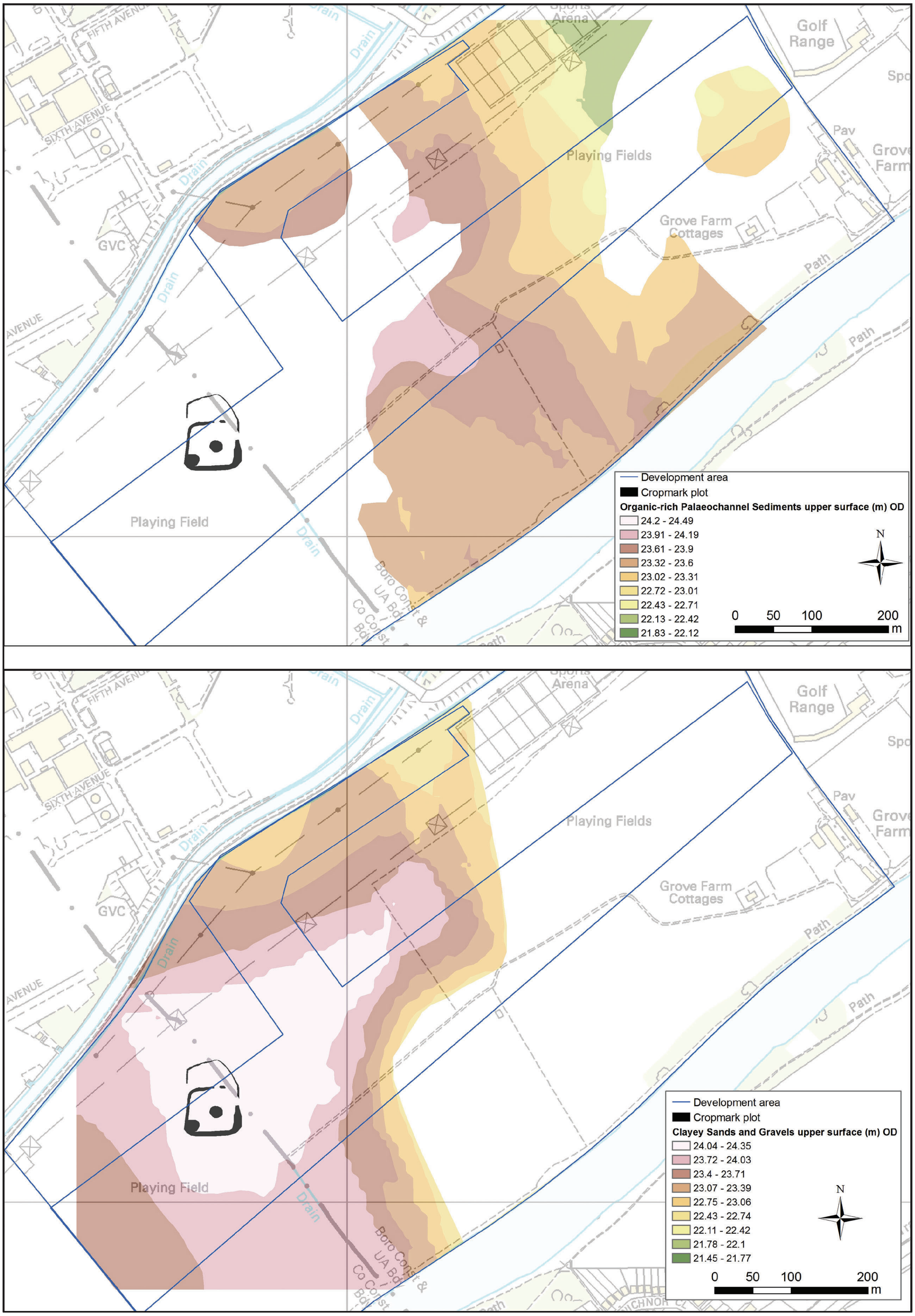

Figure 6.4: The modelled upper surface of the Organic-rich Palaeochannel Sediments (A) and the modelled upper surface of the Clayey Sands and Gravels (B; HMSO Crown Copyright, OS licence no. 100019139)

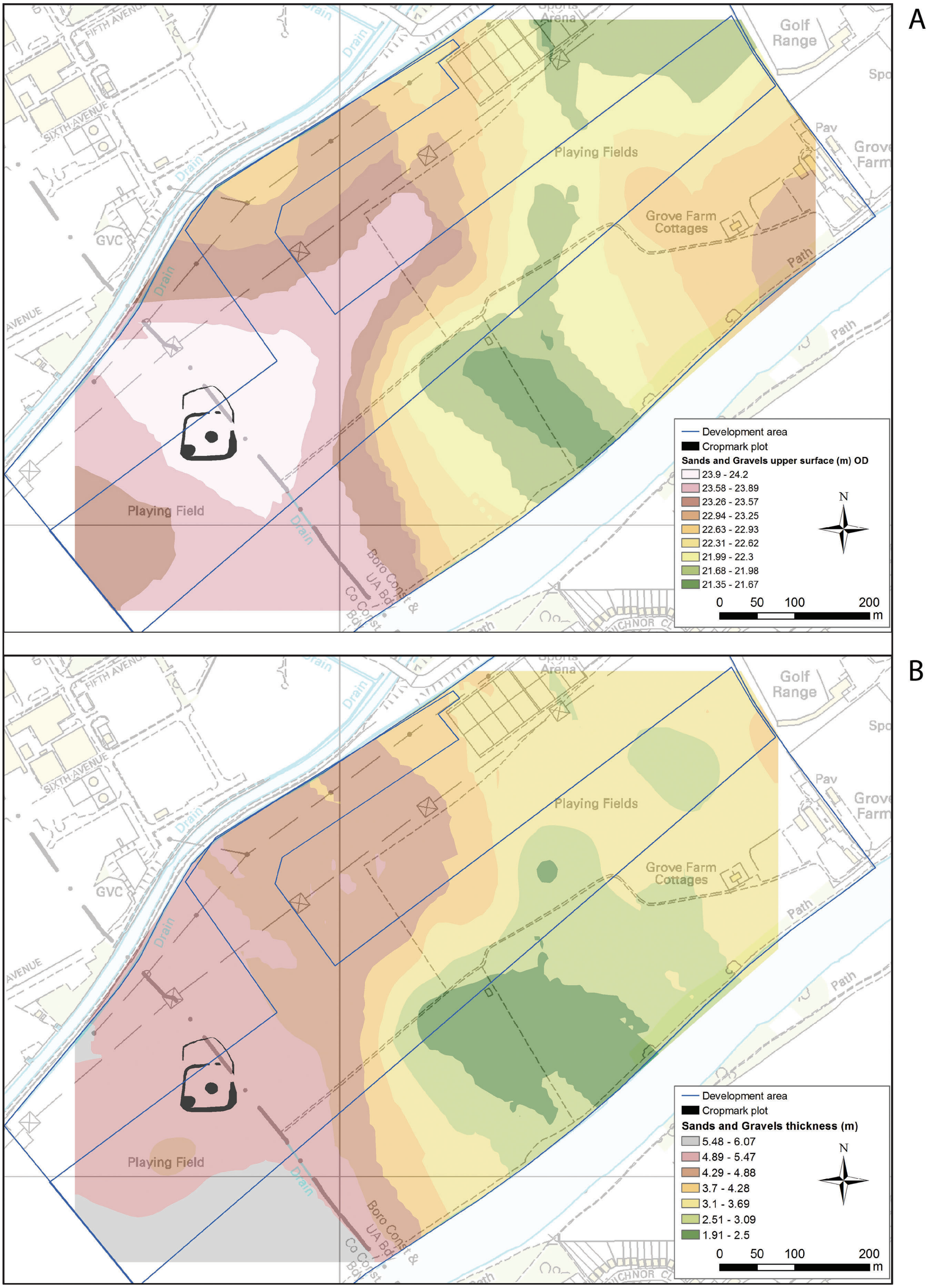

Figure 6.5: The modelled upper surface (A) and thickness (B) of the Sands and Gravels stratigraphic unit (HMSO Crown Copyright, OS licence no. 100019139)

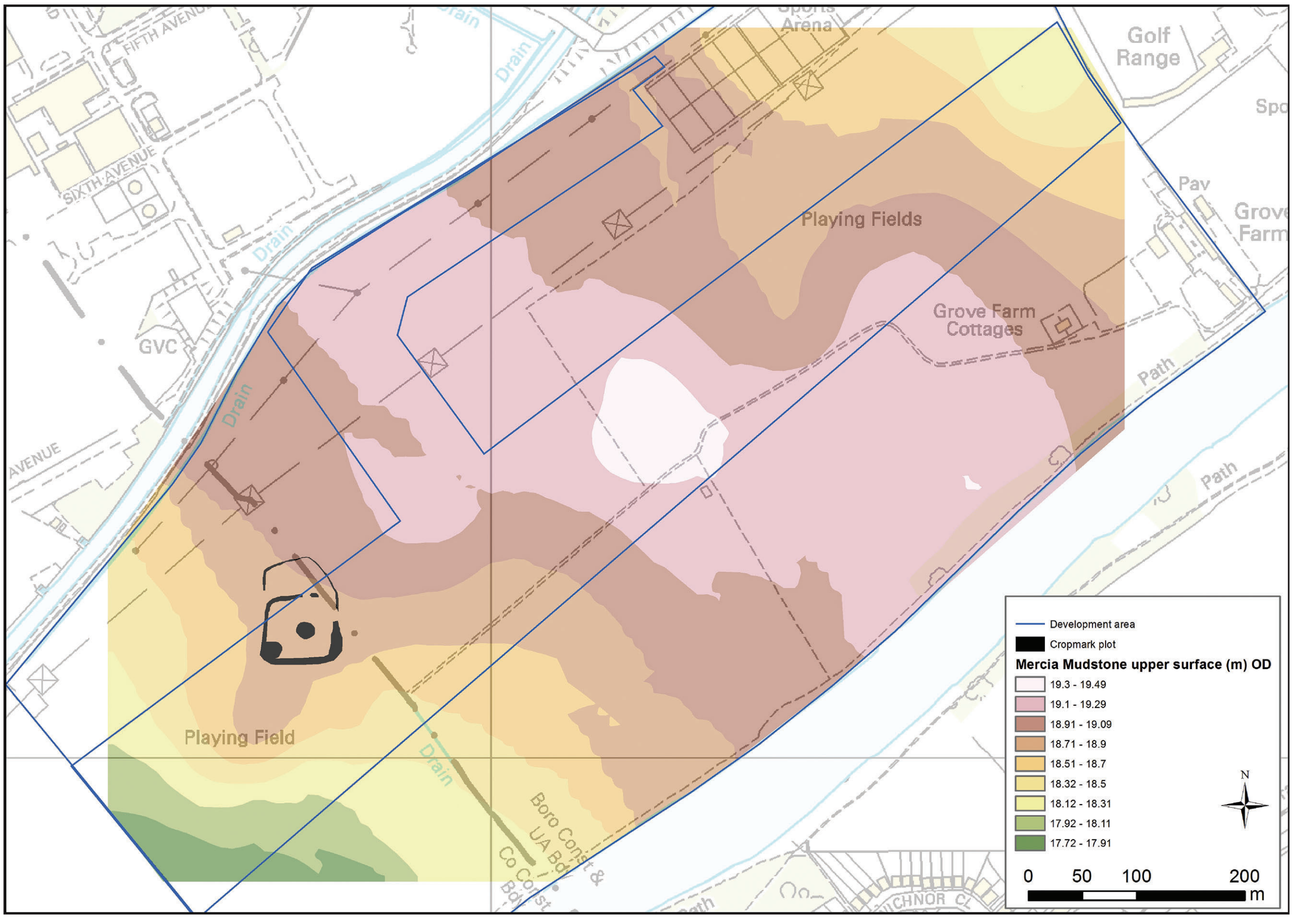

Figure 6.6: The top surface of the Mercia Mudstone bedrock (HMSO Crown Copyright, OS licence no. 100019139

A linear band of this deposit, indicating an infilled palaeochannel that would originally have flowed across the development area, was recorded towards the centre of the site. The age and exact orientation of this palaeochannel could not be determined during the course of fieldwork, but importantly it preserved a sequence of organic-rich fills to a depth of 5.3m BGL. A seemingly discrete deposit of similar material, interpreted as possibly further evidence for channel activity, was found towards the east of the development area.

- *Clayey sands and gravels* (Figure 6.4b)
  This deposit was found at the top of the sands and gravels in the west of the development area. It extended typically to a maximum depth of *c* 1.5m BGL and comprised a stiff clay matrix with small pea gravel and sand. This deposit is distinct from the underling sands and gravels, and could represent fluvial reworking of the underlying terrace surface or the impact of contemporary weathering processes.

- *Sands and gravels* (Figure 6.5a&b)
  These consisted of rounded to sub-angular gravel clasts, with a considerable component of orange-brown, fine to medium sand. This sand and gravel was often matrix-supported. Intermittent sandy deposits, interpreted as bar top sediments, were recorded overlying this unit. This material formed a thick terrace deposit in the western half of the development area. In contrast, the eastern side of the area was characterised by notably thinner sand and gravel deposits, indicating erosion of the terrace across that part of the site.

- *Mercia Mudstone bedrock* (Figure 6.6)
  This lithological unit represents the top of the underlying Triassic mudstone bedrock. Its surface represents a late Pleistocene planation surface, and could potentially be associated with Middle or Upper Palaeolithic archaeological remains on its surface. An area of deeper incision was preserved in the bedrock in the middle of the development area, corresponding with the course of the major palaeochannel that has been described above.

6.4.2. Geomorphic zones deduced from borehole data

From the description and mapping of the macro-stratigraphic sediment units described above, four

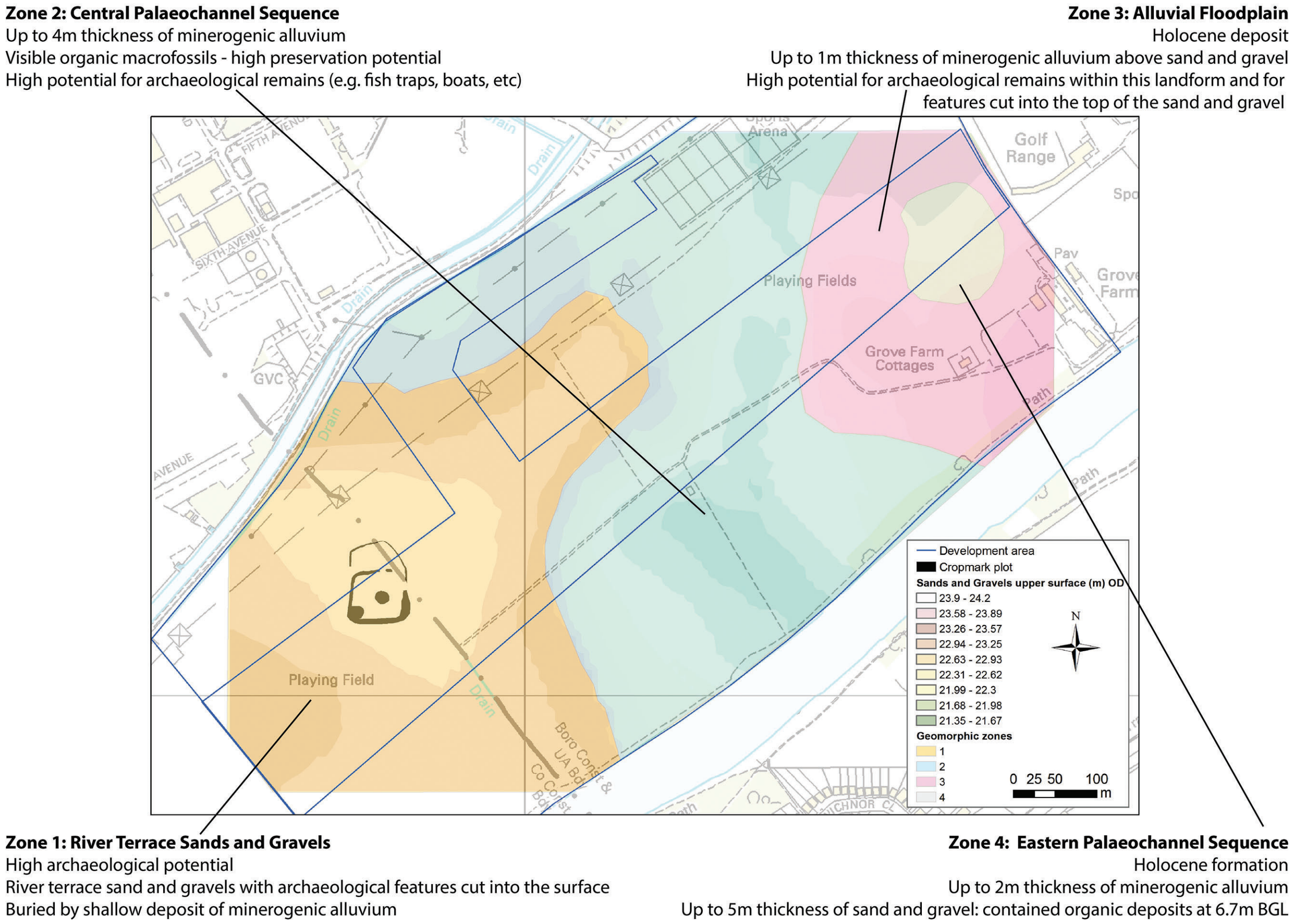

Figure 6.7: The geomorphic zonation of the site and summary of archaeological potential, compiled after the completion of ground investigations (HMSO Crown Copyright, OS licence no. 100019139)

geomorphic zones with variable archaeological and palaeoenvironmental potential were defined. All were sealed by variable depths of light brown silty clay alluvium that on the higher river terrace and along the edge of the floodplain merged into an upper ploughed horizon of brown-grey silty clay (Figure 8: deposits 1 and 2). The distribution of these geomorphic zones is shown in Figure 6.7, while their sediment stratigraphy and architecture is illustrated in a representative south-west to north-east cross-section across the site (Figure 6.8).

Zone 1 (river terrace sands and gravels): area of river terrace sands and gravels, extending to a maximum depth of *c* 8m BGL and masked by shallow minerogenic alluvium with a ploughed A horizon (to a maximum depth of *c* 1m BGL). This elevated topographic zone was attributed tentatively to the late Pleistocene Holme Pierrepont Sand and Gravel (Bridgland *et al* 2014, 26–32); it was suggested that the overlying clayey sands and gravels described in Chapter 6.4.1 could signify reworking of the late Pleistocene terrace surface or perhaps just coeval weathering processes.

The terrace deposit has a very high potential for the preservation of archaeological features cut into the terrace and/or preserved beneath alluvium, as demonstrated by the available air photographic evidence. This reveals cropmarks indicative of archaeological features across the terrace, including an enclosure complex at the highest point of the landform. This cropmark complex invites close comparison on typological grounds with Iron Age and Romano-British occupation foci along the Trent Valley, suggesting that as elsewhere in the Valley the river terrace may have provided an attractive focus for settlement during these periods (Knight and Howard 2004, 79–151).

Zone 2 (central palaeochannel sequence): major palaeochannel complex, characterised by a band of deeper minerogenic alluvial deposits above the sands and gravels (to *c* 4.5m BGL), with areas of significant organic preservation and high palaeoenvironmental potential. The underlying sand and gravel deposits are significantly thinner, ranging in depth from *c* 4.5–7m BGL. Zone 2 is topographically lower than Zone 1, and coincides with the location of one or more palaeochannels that have incised into the underlying sands and gravels. The channel deposits preserve organic-rich sediments with significant potential for elucidating changes in the valley environment. The cross-section (Fig.6.8b) could signify two palaeochannels, coinciding respectively with boreholes CC31 and

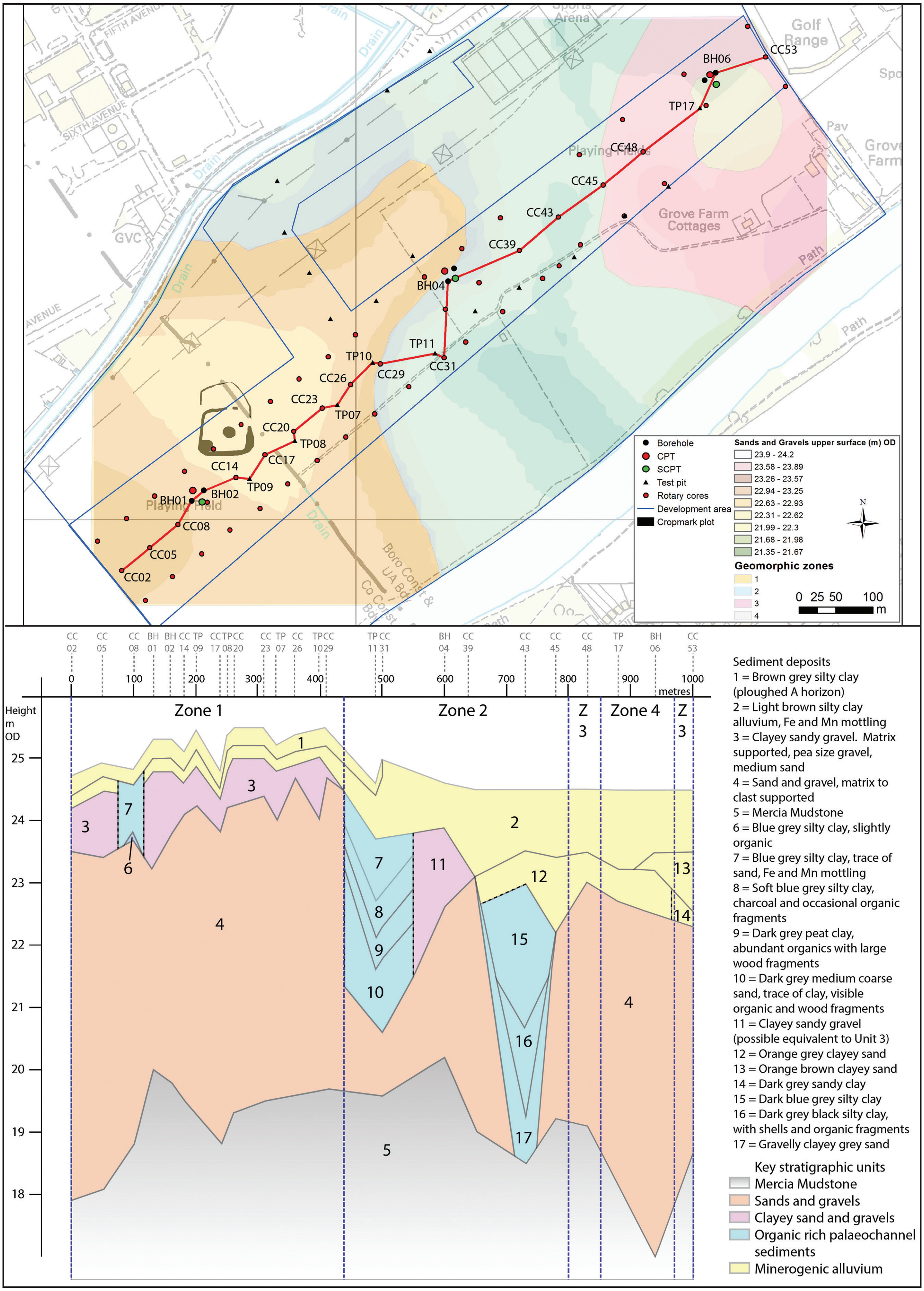

Figure 6.8: West-east cross-section of the development area, showing the four geomorphic zones and the locations of borehole (BH), test-pit (TP) and rotary core (CC) records used to construct the cross-section (CPT: cone penetration test; SCPT: seismic cone penetration test; HMSO Crown Copyright, OS licence no. 100019139)

Table 6.1: Summary of archaeological and palaeoenvironmental potential of the geomorphic zones deduced from analysis of the borehole data

Geomorphic zone	Key stratigraphic unit	Main lithology	Archaeological potential and indicative date	Palaeoenvironmental potential	Indicative depth below ground level (BGL)
1 River terrace sands and gravels	Minerogenic alluvium	Brown-grey silty clay with Fe and Mn mottling	Low **Holocene**	Low	0 – 0.4m BGL
	Clayey sands and gravels	Brown-grey, stiff and concreted clayey sand with small gravel clasts	High: multiperiod archaeological remains cut into/above the surface **Late Pleistocene to Early/Mid Holocene**	Low	0.4 – 1.3m BGL
	Sands and gravels	Rounded to sub-angular clasts in orange to grey, fine to medium sand	High: multiperiod archaeological remains cut into/above the surface **Late Pleistocene (Holme Pierrepont Member)**	Low to moderate	1.3 – 7.0m BGL
2 Central palaeo-channel sequence	Minerogenic alluvium	Brown-grey silty clay with Fe and Mn mottling	Low **Holocene**	Low	0 – 1.0m BGL
	Organic-rich palaeochannel sediments	Blue to grey silty clay and clayey sand, often with visible organic remains	High: multiperiod archaeological remains stratified in sediment matrix (eg fishweirs, logboats, bridges & trackways) **Holocene**	High	1.0 – 5.3m BGL
	Sands and gravels	Rounded to sub-angular clasts in orange to grey, fine to medium sand	Moderate: multiperiod archaeological remains; character dependent on date of gravel **Late Pleistocene (Holme Pierrepont Member)**	Low to moderate	5.3 – 7.0m BGL
3 Alluvial floodplain	Minerogenic alluvium	Brown grey silty clay with Fe and Mn mottling	Low **Holocene**	Low	0 – 0.2m BGL
	Minerogenic alluvium	Light brown to grey sand silt, with clay	Unknown **Holocene**	Low	0.2 – 1.0m BGL
	Sands and gravels	Rounded to sub-angular clasts in orange to grey, fine to medium sand	Moderate: sands and gravels tentatively dated to the Holocene **Holocene?**	Low to moderate	1.0 – 6.0m BGL
4 Possible eastern palaeo-channel sequence	Minerogenic alluvium	Brown grey silty clay with Fe and Mn mottling	Low **Holocene**	Low	0 – 0-1m BGL
	Minerogenic alluvium	Light brown to grey clay silt with sand	Unknown **Holocene**	Low	0.1 – 2.0 m BGL
	Sands and gravels	Rounded to sub-angular clasts in orange to grey, fine to medium sand; associated organic remains	Moderate: sands and gravels tentatively dated to the Holocene **Holocene?**	Low to moderate	2.0 – 7.0m BGL

CC43, or alternatively these depressions might relate to a single meandering channel. Both the cross-section and plan (Figure 6.8a) suggest additional complexity in this palaeochannel zone, which includes a clayey sandy gravel (11) that might correspond to layer 3 in Zone 1 and an orange-grey clayey sand (12), possibly of alluvial origin, that was observed to extend eastwards into Zones 3 and 4. Further work would be required, however, to investigate the origins of these deposits and their relationships to the palaeochannel deposits identified in Zone 2 and the channel sequence postulated in Zone 4 (below).

Zone 3 (alluvial floodplain): topographically low floodplain, characterised by slightly deeper minerogenic alluvial deposits above sands and gravels than were recorded on the Zone 1 river terrace. These do not extend as deeply as the alluvial deposits observed in Zones 2 and 4, but in common with those areas preserve beneath light brown silty clay alluvium (Figure 8b: deposit 2) a sequence of sandy and silty clays (deposits 12, 13 and 14).

Zone 4 (possible eastern palaeochannel sequence): second zone of deeper minerogenic alluvial deposits above the sands and gravels, encircled by deposits attributed to Zone 3 and differentiated only slightly from deposits attributed to that zone. Interpretation is problematic, but the subsurface topography suggested at the time of survey that these deeper alluvial deposits might correlate with another palaeochannel sequence. Organic remains were found at a depth of 6.7m BGL within the underlying sand and gravel unit in Borehole 06, indicating a probable Holocene date for these deposits.

Identification of the above geomorphic zones suggested division of the site into several discrete depositional environments with variable archaeological and palaeoenvironmental potential, as summarised in Table 6.2. This provided the framework for the gradiometer survey which is discussed in the following section.

6.5. Gradiometer survey (Stage 3): refining the deposit model

Following modelling of the subsurface deposits, a gradiometer survey was conducted with the aim of defining more precisely the range of archaeological features that might survive within the application area and the spatial extent of the geomorphic zones identified by the borehole survey (Table 6.2). The survey was conducted at this stage of the project on the grounds that knowledge of variations in the depth of alluvial cover would permit a more informed interpretation of the results of the technique than would otherwise have been possible. Gradiometer data may be expected to reveal archaeological features only to a depth of *c* 1m BGL, whereas it was known that up to 7m of Holocene sediments had infilled parts of this development area. This 1m depth penetration was entirely appropriate, therefore, for defining archaeological features sealed by shallow masking deposits, notably in Zone 1, but beyond such areas discontinuities in the distribution of archaeological features should be interpreted with caution.

Table 6.2. Rationale for collection of the gradiometer data across the different geomorphic zones

Zone	Rationale for gradiometer survey
1	Define archaeological remains on the terrace (could be cut into clayey sands and gravels from *c* 0.4m BGL) and at the interface between Zone 1 (terrace) and Zone 2 (palaeochannel)
2	Define the area of Zone 2 palaeochannel and its interfaces with Zones 1 and 3
3	Prospect for archaeological features cut into the surface of the gravels (recorded at a level of *c* 1.0m BGL) and define this zone more precisely
4	Define more closely the spatial extent of this zone

The gradiometer survey defined successfully multiple groups of potential archaeological features within areas characterised by shallow alluvial cover, adding significantly thereby to our understanding of the archaeological resource (Figures 6.9 and 6.10). The late prehistoric/Romano-British enclosure complex on the gravel terrace of Zone 1, with its traces of possible roundhouses and field boundaries, is particularly noteworthy, together with traces of another small palaeochannel that could be shown cutting into Zone 1 and possible building debris at the edge of the former channel. A possible trackway was shown traversing the lower floodplain in Zone 3. In addition, the interface between Zones 1 and 2 was defined more closely by the gradiometer data; the plot of magnetic anomalies reveals the same general trend as indicated by the borehole data, but locates the edge of the interface more precisely, slightly farther to the east of the boundary that was postulated from the borehole survey (Figure 6.10). The deposit model was refined after completion of the gradiometer survey, with the definition of another palaeochannel zone (termed Zone 5) in the northern part of the study area and the merging of Zones 3 and 4 into a single zone (renamed Zone 3). The gradiometer survey identified in the L-shaped northern extension of the development area a linear zone that was magnetically much quieter than the Zone 1 terrace, suggesting that the higher terrace landform might have been edged on its northern side by another palaeochannel zone (Figure 6.10: termed Zone 5). In addition, it was concluded after the gradiometer survey that Zones 3 and 4 were not sufficiently distinct to be

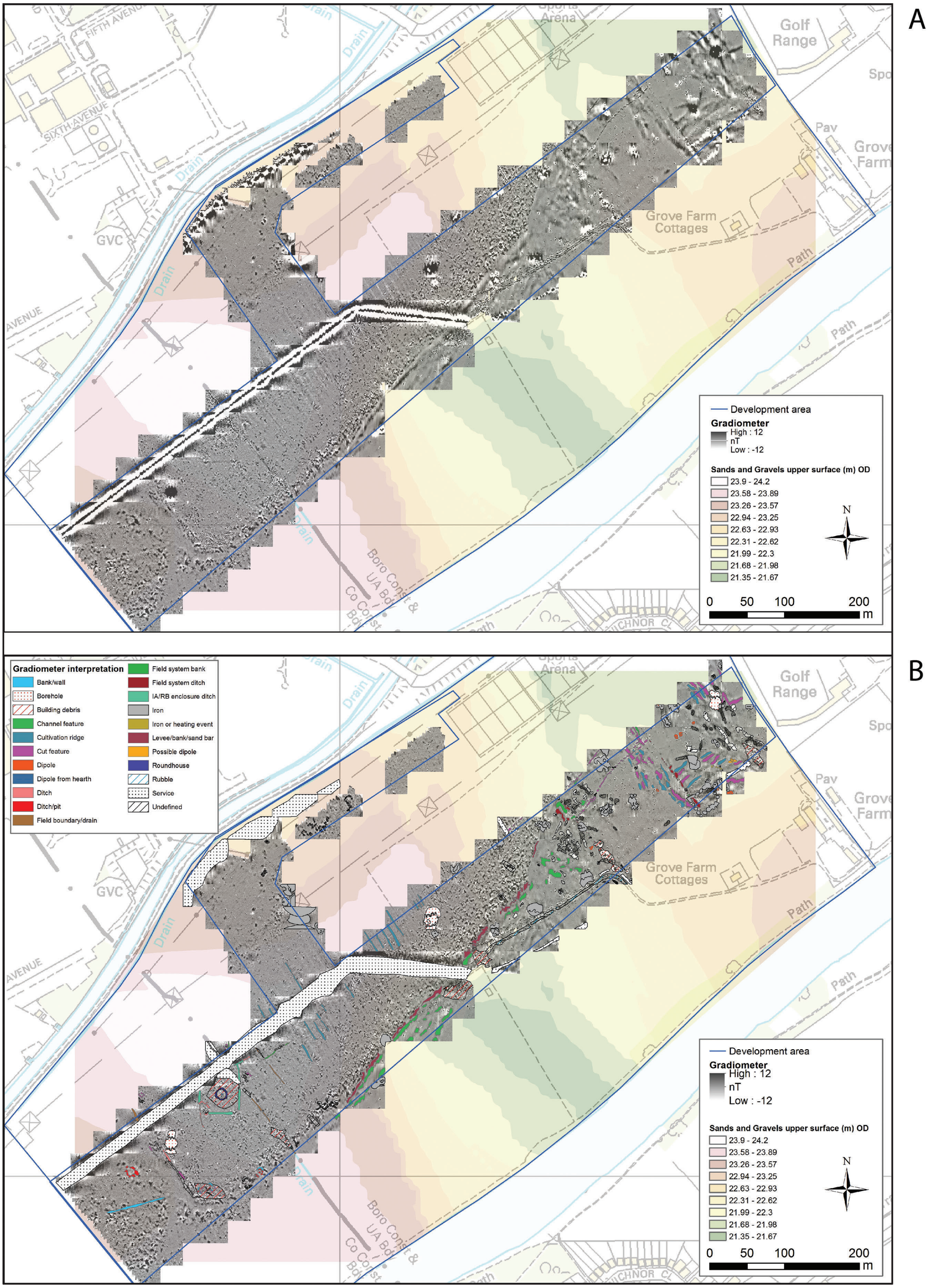

Figure 6.9: The gradiometer survey across the development area, shown as semi-transparent where it overlies the plotted upper surface of the Sands and Gravels (A) and with interpretation of the gradiometer data, showing the wealth of geomorphological and archaeological anomalies (B; HMSO Crown Copyright, OS licence no. 100019139)

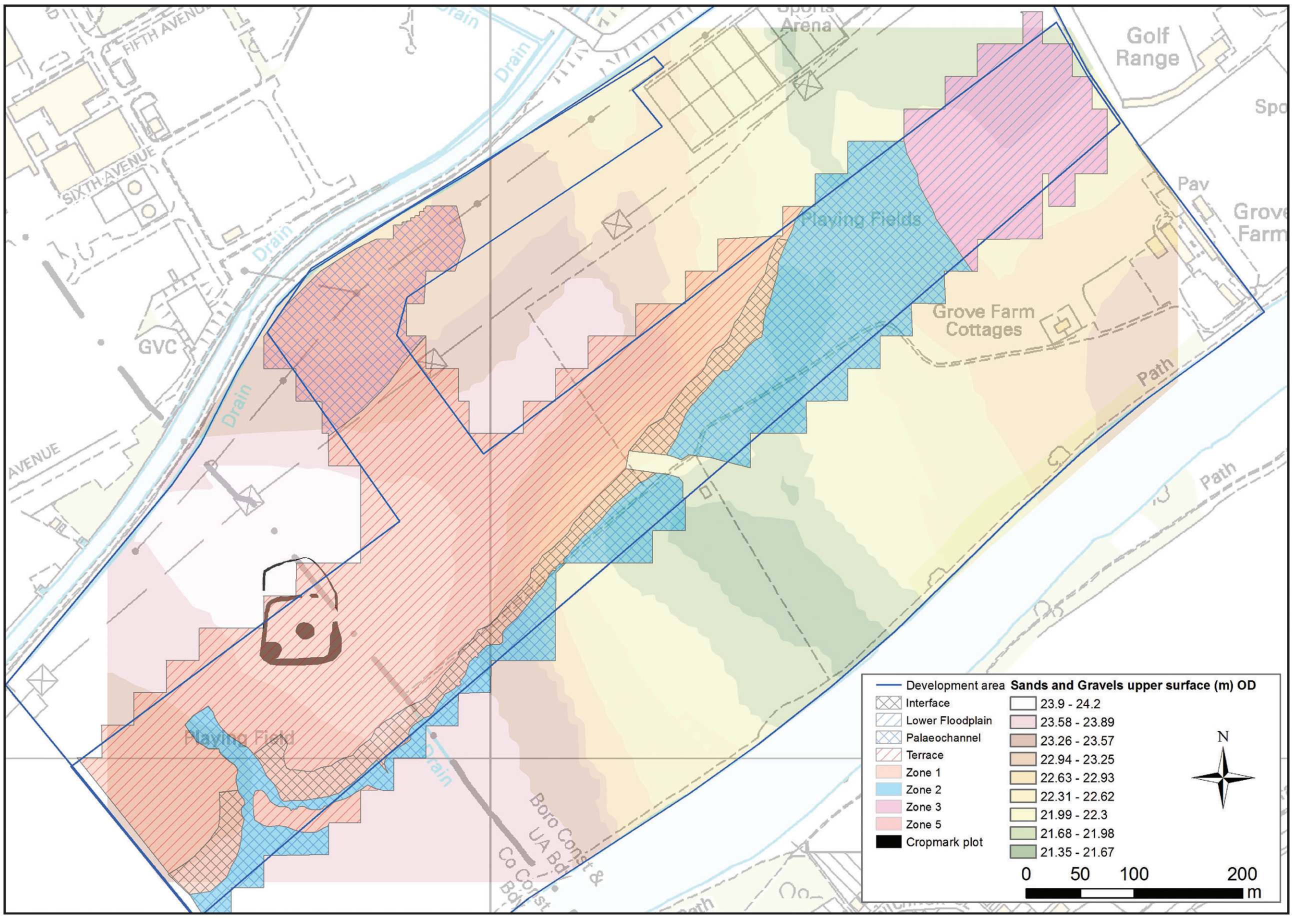

Figure 6.10: Revised geomorphic zonation of the development area, refined by reference to the gradiometric data (HMSO Crown Copyright, OS licence no. 100019139)

identified as different zones and were better interpreted as constituents of a Holocene floodplain landform (Zone 3). The gradiometry survey was successful, therefore, in refining our understanding of the archaeological and geoarchaeological resource and emphasises the value of detailed geophysical survey as a tool for the deposit modeller.

6.6. Conclusions: combining borehole data and gradiometry

The borehole and gradiometry surveys provided crucial data for understanding the subsurface topography and stratigraphy of the proposed windfarm development and enabled the developer and consultant to assess clearly, in consultation with the regional archaeological curators, the required scale of further evaluation and mitigation work. It was decided, in view of the results of these investigations, not to proceed further with the development, and no additional work has been conducted in this area since completion of the gradiometry survey in 2011. Many questions remain regarding the development of this landscape and its exploitation by human communities, but the procedures adopted have emphasised the value of a staged approach to the development of a deposit model that could then inform future action. Without this model, the risks of development could not have been quantified and a reasoned decision on how best to proceed could not have been made. In this respect, the approach can be seen as an exemplar for establishing optimum evaluation and mitigation strategies, providing a methodology on how to proceed with site investigations in advance of development in alluvial environments whose archaeological and palaeoenvironmental potential is hidden firmly from view.

The primary data and reports generated by this project have been deposited in Nottingham City Museum (accession No. NCMG 2011-44). Copies of the project reports may also be consulted by application to the Nottinghamshire County Council Historic Environment Record and are available in digital format from the Archaeology Data Service (Carey and Knight 2011 a, b and c).

Acknowledgements

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Constructing a geoarchaeological deposit model: Grove Farm, Nottingham

↓

Assess pre-existing data

- British Geological Survey mapping
- Aerial photographs
- Lidar data: not available to project at the time of survey

↓

Develop rationale for model construction and key aims/objectives

- Understand Holocene sediment sequences
- Define archaeological potential
- Recognise different depositional environments

↓

Can the deposit model be constructed using pre-existing data?

No

↓

Commission further ground investigations, including:

- Additional purposive boreholes and recording of geotechnical boreholes and test pits

↓

Construct deposit model comprising one or more of the following:

- Interpolation of key macro-stratigraphic sediment units' upper surfaces
- Interpolation of key macro-stratigraphic sediment units' thicknesses
- Representative cross-section across the application area

↓

Ground truth deposit model through fieldwork and relate back to rationale of project aims and objectives

- Gradiometer survey used to define archaeological features and refine deposit model.

↓

Revise final product

Deposit model updated with the gradiometer data and a further report issued.

↓

Archive and re-use

Data and reports archived with Nottingham City Council, Nottinghamshire HER and the Archaeology Data Service

7. Geoarchaeological deposit modelling, New Covent Garden Market, Wandsworth, London

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Abstract

Redevelopment of the New Covent Garden Market site, Wandsworth, London, required the production of a deposit model to map the subsurface sediments and topography as a guide for geoarchaeological and archaeological works in advance of a multi-phased construction project. The deposit model was based on 444 data points comprising existing borehole records held by the British Geological Survey (BGS), geotechnical site investigations and data shared by partners also working within the area, which has been the focus of major urban regeneration with co-operation achieved under the banner of the Battersea Channel Project. The deposit model established a series of key deposit types representing distinct depositional environments. The model identified a series of sand and gravel highs and lows, representing small, relatively drier islands within a landscape of low-lying wetland dissected by channels infilled later with peat and alluvium, and sealed by alluvial deposits associated with the development of the contemporary Thames floodplain. The sand and gravel islands (eyots) and channel edges would have provided attractive locations for human activity and occupation, with deposits of high palaeoenvironmental potential located within the channel areas. The deposit model was used to direct subsequent archaeological trial trenching that will take place over several stages as the development progresses, with the results fed back into the deposit model.

7.1. Introduction

Modelling of the deposits underlying the New Covent Garden Market (NCGM) and surrounding area was undertaken in advance of a multi-phase construction project to redevelop the iconic fruit, vegetable and flower market (Figure 7.1). The site occupies 23 hectares of urban land within the London Borough of Wandsworth, forming the eastern part of the Nine Elms redevelopment: an area encompassing 227 hectares of land extending westwards along the south bank of the River Thames. The NCGM site sits squarely within the boundaries of the Battersea Channel Project: a collaborative project initiated by English Heritage (2014, 2015), now Historic England, to examine a now infilled former channel hypothesised to represent a previous course of the River Thames and discussed in more detail elsewhere in this volume (Yendell, Chapter 11). Deposit modelling at the NCGM site commenced subsequent to initial geotechnical Site Investigations (SI), as part of a geoarchaeological Desk-Based Assessment (DBA) combining past and present SI data, British Geological Survey (BGS) records, and nearby data shared from partners working within the Battersea Channel Project area.

7.2. Aims and objectives

The aim of the deposit modelling was to map the subsurface topography, particularly sand and gravel islands and associated channels, characterise the key deposits and identify areas of differing geoarchaeological and archaeological potential. The results will be used to guide further archaeological and geoarchaeological works, including archaeological trial trenching and mitigation, as well as borehole survey for palaeoenvironmental assessment and dating purposes. Results from each stage of works will be used to update the deposit model as the project progresses.

Mapping by the BGS, along with more recent developer-funded investigations across the Nine Elms area suggest a complex Late Pleistocene and Holocene palaeolandscape (Branch *et al* 2010; Green and Young 2011; Morley 2010; Young *et al* 2012, 2013). Networks of interweaving infilled channels rest on and are incised

Comparative data table of this deposit model	
Deposit model location	Wandsworth, London, UK (NGR 529703 177213)
Depositional environment	Late Pleistocene, braided, cold climate channel topography overlain by Holocene floodplain alluvium
Size of deposit model	Site *c* 25Ha; deposit model *c* 100Ha
Data collection strategies	Combination of BGS online logs, new and historic site investigation data, data points shared by other Battersea Channel Project Forum members
Position in the archaeological process	From desk-based assessment stage through geoarchaeological field survey, evaluation and mitigation
Reason for deposit model construction	To model the subsurface topography, particularly the location of gravel islands and associated channels/ low-lying wetland areas, to characterise the key deposits and identify areas of environmental and archaeological potential as a guide for further geoarchaeological works and archaeological trial trenching
Archaeological question	Determine the presence and location of gravel and sand islands and associated channels. Does the evidence support the hypothesised Battersea Channel? How did these channels shape the prehistoric landscape? How were the channels changed by processes such as sea-level rise? Is there evidence for human activity and occupation?
Software and modelling process	Data was entered into Rockworks, modelled and displayed in ArcGIS
Outputs from the deposit model	Digital elevation models (DEMs) and 2-dimensional representations of sediments through deposit records linked along a transect

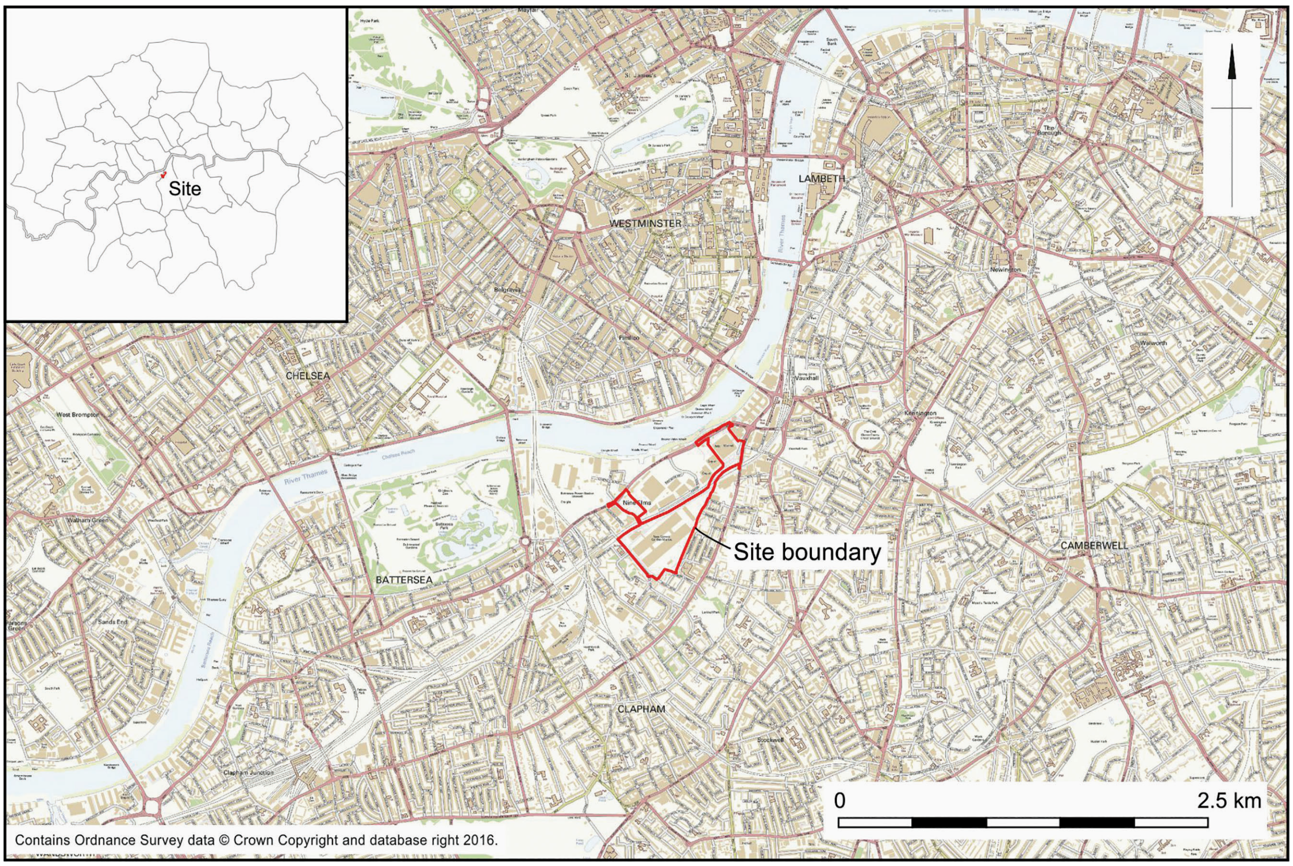

Figure 7.1: Location of the New Covent Garden Market site demarcated by the thick red line, Wandsworth, London

into an uneven underlying surface of sands and gravels of Late Devensian date (Gibbard 1994), which in some places are elevated to form islands (also termed eyots) of higher dry ground between the channels. These eyots are progressively sealed by Holocene alluvial deposits of the Lower Thames floodplain, comprising sands, silts, clays and peats. Radiocarbon dating of peats has shown them to vary widely in age, primarily from the Late Mesolithic to Bronze Age (Young *et al* 2012, 2013), but with rare deposits of Late Glacial date (Morley 2010) from channel deposits located *c* 0.5km south-west of the NCGM site.

There are certain issues with the use of the term 'channel' with regard to the low-lying features between areas of raised sand and gravel. When considering the floodplains of the Thames, it is important to remember that the sand and gravel topography being studied is the remnant of a fossilised, high energy cold-climate braided river system. The natural features commonly observed and referred to as channels between raised gravel islands – and which were almost certainly part of a high-energy channel system during the Pleistocene – may or may not actually have been active channels *per se* at any point during the Holocene. Any Holocene fluvial activity taking place will be largely constrained by this topography – and of course modify it – but the features themselves are not necessarily a result of this activity. If never disturbed by significant discharge during the Holocene, these relict channel areas would have infilled as groundwater levels rose during the Holocene, forming low-lying wetland areas between gravel highs, and accumulating alluvium during higher energy flood events.

The potential for the formation of such sediment units over prolonged time periods is reflected in the wide variation between radiocarbon dates obtained from the deposits within these low-lying areas, as they are variously occupied and abandoned by Holocene channel activity, or indeed – in the case of those with Late Glacial or Early Holocene peat deposits – probably never reactivated at all.

Determining the location, orientation, depth and extent of key deposits and features through modelling is fundamental to establishing the archaeological potential of the deposits and understanding the development of the prehistoric landscape. The areas of higher, dry ground, along with the channel edges, would have been attractive locations for human exploitation and occupation and have an increased probability of containing evidence of prehistoric activity (English Heritage 2014, 2015). Occupation of the gravel terraces is known approximately 200m to the east of the NCGM site in the form of Neolithic to Iron Age pits and flint scatters. Moreover, the channel and floodplain deposits are likely to include organic deposits capable of providing proxy evidence for palaeoenvironmental reconstruction and to preserve wooden structural remains such as causeways and trackways. Prehistoric timber structures have been identified less than a kilometre to the north-east of the NCGM site on the foreshore of the Thames at Vauxhall Bridge, including wooden piles of Mesolithic and Bronze Age date. One of these former Late Pleistocene/Early Holocene channels – first termed by Morley (2010) as the Battersea Channel – forms a significant natural feature of the NCGM site. The deposit modelling undertaken as part of this project provides an opportunity to examine the evidence for the Battersea Channel, as well as associated channels and sand and gravel eyots.

7.3. Methodology

The deposit model is based on 444 data points (borehole and test pit logs) from the NCGM site and surrounding area (Figures 7.2, 7.3, 7.4 and 7.5). Modelling was undertaken as a geoarchaeological DBA and benefitted from access to 232 BGS boreholes, 88 data points available as part of the Battersea Channel Project, 113 points from geotechnical SI data and – at the time of writing – a further six evaluation trenches and five boreholes undertaken by Wessex Archaeology (2015). The individual deposit records were examined by a geoarchaeologist and entered into a digital database (Rockworks 17). Based on the accumulated lithological evidence, the data were grouped into a set of stratigraphic units in order to map the key deposits across the site. The data were modelled using an inverse distance weighting algorithm within Rockworks. The Rockworks data was exported into Arc GIS (v10.1) and used to create digital elevation models (DEMs), thickness plots and surface horizons, and a south-east to north-west orientated transect showing the key deposits (Figures 7.2-7.6) in order to map the subsurface topography of the site.

7.4. Results and interpretation

The key stratigraphic units identified during examination of the various deposit records follow closely those used by partner organisations working at nearby sites (R. Batchelor, Quest, pers. comm.) and are discussed and interpreted below. These deposits are used to reconstruct a picture of the evolving physical landscape across the NCGM site and surrounding area over the course of the Late Pleistocene and Holocene.

Upper alluvium

This sediment is a dark greenish-grey silty and sometimes sandy-clay unit largely devoid of visible organic remains. It is widely distributed across the site except in areas of sand and gravel highs or where the alluvium has been truncated by later human activity.

Peat

Peat deposits are present locally across the site and largely comprise well humified black, structureless, silty clay peats containing occasional and often unidentifiable wood and/or herbaceous plant remains. Peat deposits from two boreholes taken by Wessex Archaeology (2015), which are currently the subject of palaeoenvironmental assessment,

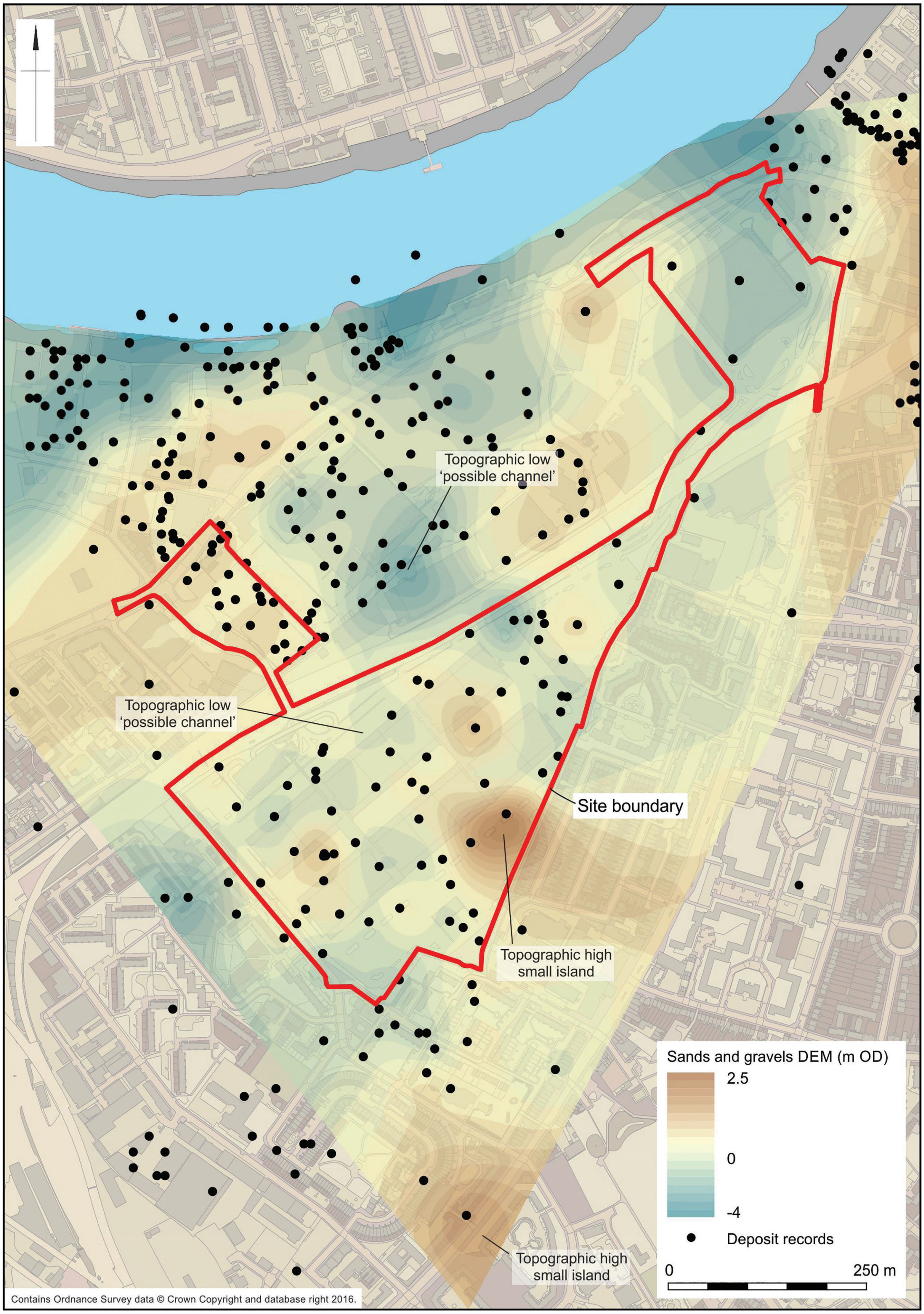

Figure 7.2: Digital Elevation Model of the upper surface of the sands and gravels for the development site and surrounding area

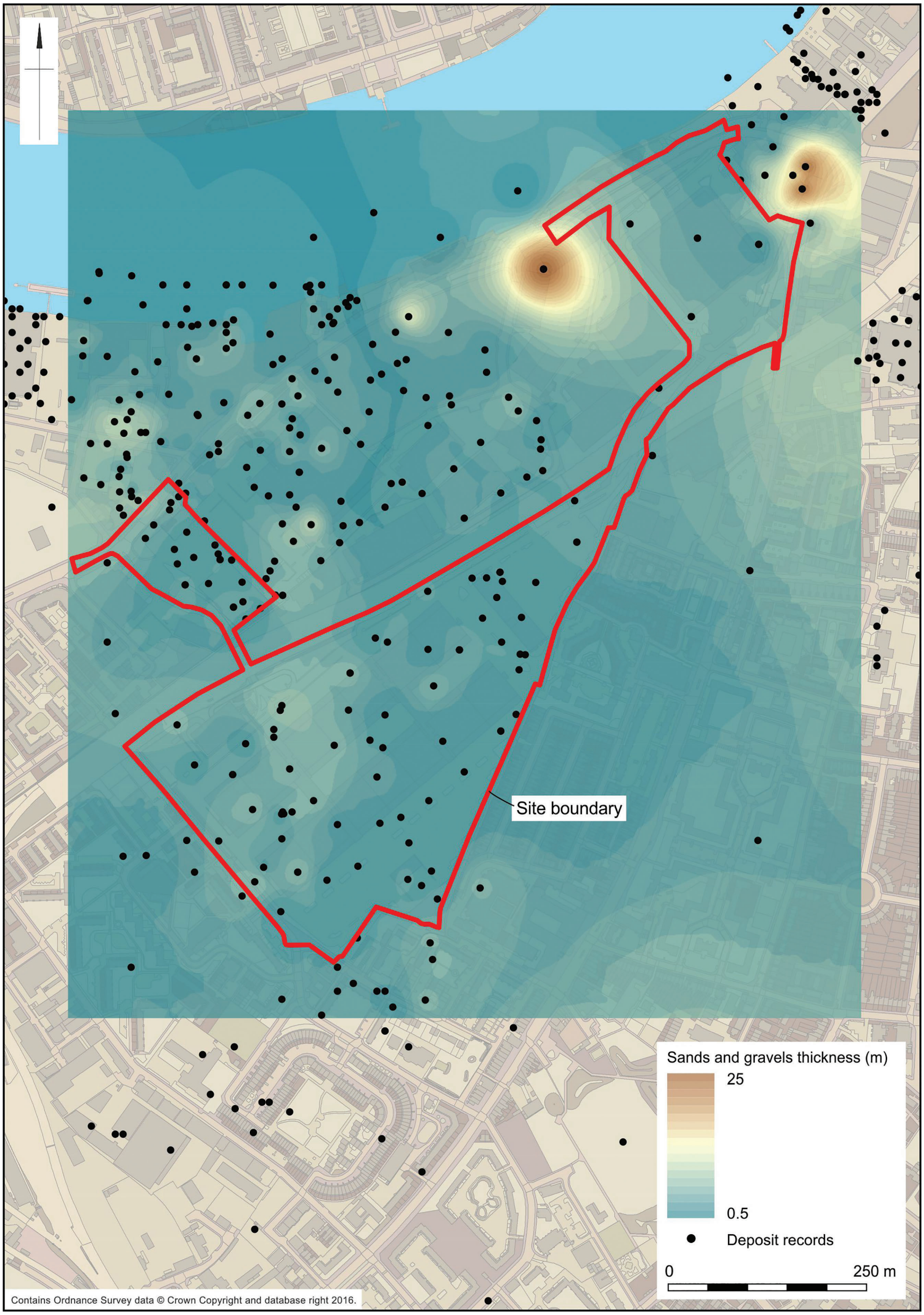

Figure 7.3: Modelled thickness of the sands and gravels for the development site and surrounding area

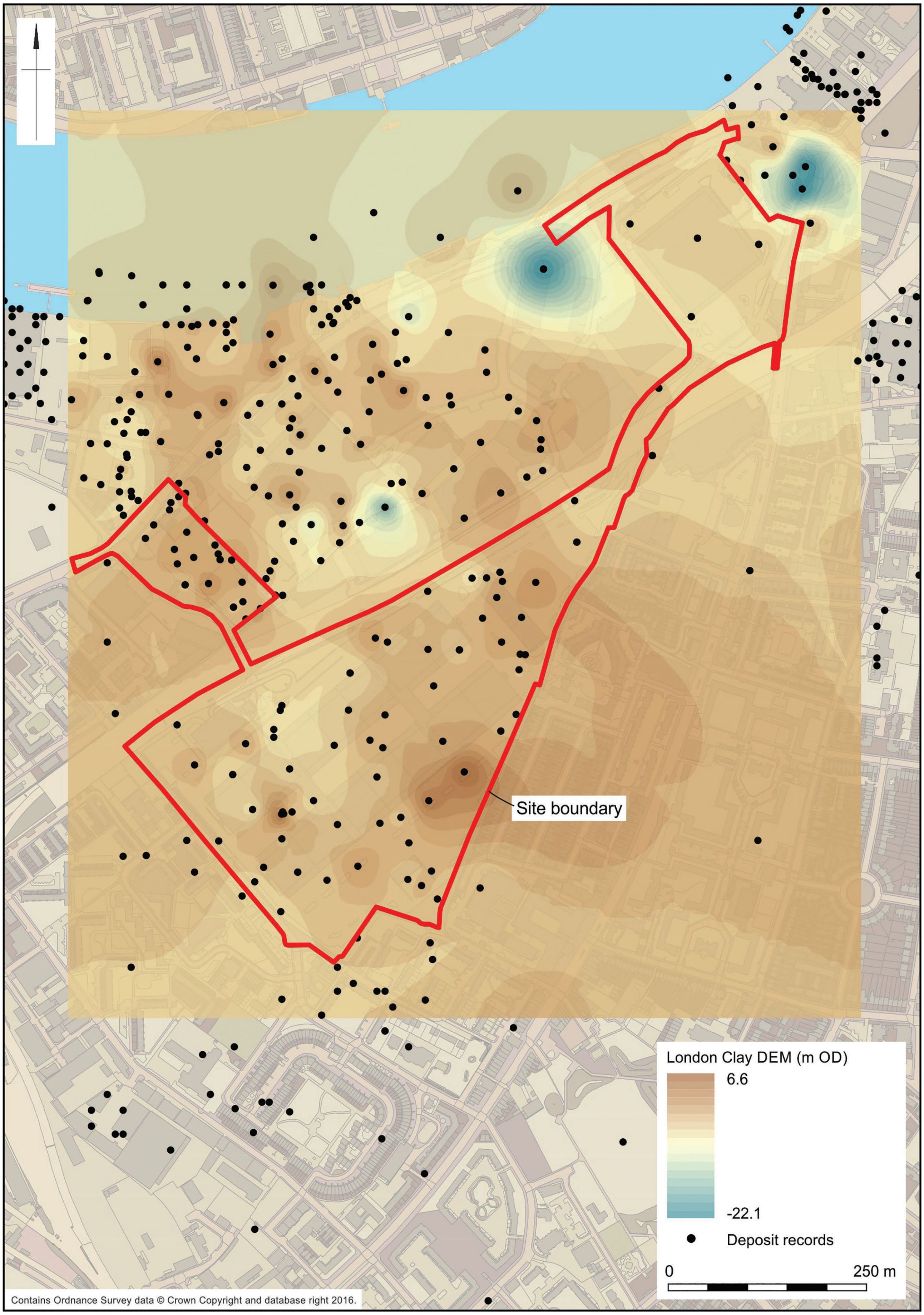

Figure 7.4: Digital Elevation Model of the upper surface of the London Clay bedrock

Figure 7.5: The distribution of organic deposits recorded within the development site and surrounding area

have been dated to the Mesolithic, Early Neolithic and Middle Bronze Age. The radiocarbon dates demonstrate that conditions for peat formation were present at various times during the middle Holocene, most probably within or capping abandoned channels across the active Thames floodplain.

Lower alluvium
The lower alluvium is a variable dark grey to dark brown, sandy and silty unit, sometimes containing fine gravel clasts along with fragments of detrital wood, herbaceous plant remains, molluscs and occasional thin peat beds.

Sand
This unit comprises coarse-grained sands with occasional gravel clasts. In practice, however, it has been very difficult to differentiate in geotechnical records between the sand and the underlying sand and gravel unit. The thickness of sands overlying the Pleistocene deposits can be identified in surrounding areas, but within the site boundary itself little or no sand has been mapped. Further geoarchaeological coring would provide the opportunity to identify the sand unit, if present, with greater confidence and precision.

Sand and gravel
This unit consists of coarse-grained, sub-angular to sub-rounded gravels, with brown clayey sands. Depending on location and elevation, these deposits are most likely attributable to the Early-Middle Devensian Kempton Park Gravel or the Late Devensian Shepperton Gravel Formation.

London Clay bedrock
The London Clay is a stiff blueish to brown clay of Eocene date (56–34 million years old). The surface was scoured by fluvial action during the Pleistocene.

The description and mapping of the principal stratigraphic units has provided an increased understanding of the physical evolution of the landscape across and surrounding the NCGM site over the course of the Late Pleistocene and Holocene. The results of the modelling have been presented as a series of digital elevation models, and surface and thickness plots. Modelling of the surface of the London Clay (Figure 7.4) clearly shows the extent of Pleistocene fluvial scouring as a general south-south-west to north-north-east trending depression across the site, providing the landform template for the overlying Pleistocene and Holocene sediments. Of the main stratigraphic units, the Pleistocene sands and gravels are of crucial significance, effectively forming a template upon which all later deposition (and archaeological activity) occurs. This template can, to a large extent, determine the probability of encountering different kinds of archaeological remains, inform understanding of the distribution of human activity, and variations in sediment accumulation and soil formation processes. The Pleistocene sands and gravels represent fluvioglacially deposited sediments, varying in thickness from as little as 0.5m to 25m (Figure 7.3). The DEM demonstrates that the sands and gravels form a series of topographic highs and lows across the site, ranging in elevation from -4.5m to +4.5m OD (Figure 7.2); the higher areas are typically associated with the greatest corresponding unit thickness.

The areas of lower elevation may represent the locations of channels, which may have been incised into the sands and gravels during the Holocene, represent remnants of the Pleistocene braided channel system, or signify a combination of the two. These lower areas typically contain sequences of alluvium and peat (Figure 7.6), and are separated by higher facets which represent sand and gravel islands (eyots) located within the valley floor system. Investigation of similar contexts across London have demonstrated that these relatively small islands would have been drier and are often associated with archaeological remains; along with the channel margins, these areas would have represented favoured locations for prehistoric human occupation and other activities.

Higher areas of gravel are most notable to the east, south and west of the site (Figure 7.2), and may form eyots within the discrete larger channel termed the Battersea Channel by Morley (2010). It is clear, however, that the organic deposits infilling the lower areas within the sand and gravel across the site represent a series of separate, smaller accumulations, within topographic lows, which may have contained Holocene channel activity (Figure 7.6). There is, therefore, little direct evidence within the site itself to support the presence of either the Battersea Channel or a second, less-substantial west-east aligned channel. Instead the deposit modelling suggests a more complex picture reflecting a network of smaller channel features that rather than creating small eyots of dryland may have been constrained by these landforms. The channels themselves are infilled largely by alluvium, although they do contain localised thin peat units varying in date from the Late Mesolithic through to the Middle Bronze Age; these peats both infill and blanket the channels and low-lying wetland areas, and were locally colonised by semi-terrestrial plant communities.

7.5. What happened after the development of the model?

The construction of the deposit model allowed the identification of eyots and associated channel areas and provided a significant tool for informing and directing targeted archaeological and geoarchaeological on-site investigations from the initial stages of the project. The results of preliminary deposit modelling were presented in a geoarchaeological assessment report, with recommendations for a broadly north-south transect of five boreholes traversing the channels and eyots, with the aim of targeting deposits of highest palaeoenvironmental

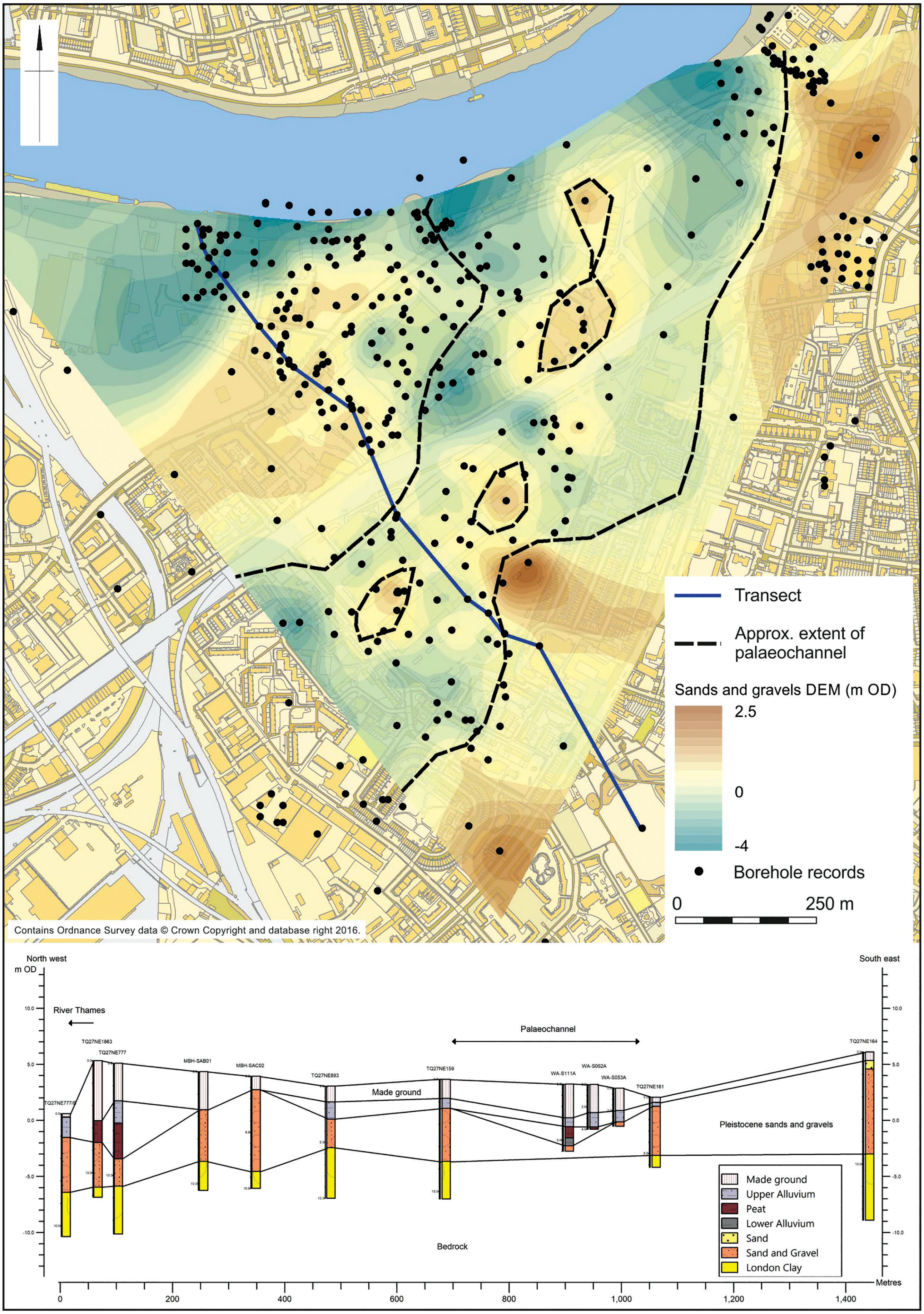

Figure 7.6: Transect showing the Holocene deposits and possible palaeochannels

potential and allowing the recovery of suitable materials for assessment and dating. The samples retrieved during the course of further fieldwork are now the subject of on-going palaeoenvironmental analysis, which will be reported on in due course, with the results fed back into interpretations of the site and surrounding area.

The deposit model was also used to direct subsequent archaeological trial trenching. These field investigations are at a relatively early stage as the development is scheduled to take place in several stages over the coming years; this approach to construction has been agreed to allow the busy working market site to continue to function during building works. Over the course of the development, the results of archaeological investigations will be fed progressively into the deposit model, which will provide a wider landscape context for the archaeological and palaeoenvironmental investigations.

The deposit model has also benefitted from the integration of geotechnical SI data from associated developments occurring across the Nine Elms redevelopment area, facilitated through collaboration under the banner of the Battersea Channel Project. This has allowed the model to be refined with contemporary data beyond the confines of the NCGM site, providing information of significance for broader discussions of the Late Pleistocene and Holocene landscape of the lower Thames basin. A forum group that was convened as part of the Battersea Channel Project has also provided an important arena for discussing the software, approaches and best practice involved in geoarchaeological deposit modelling, with regular project meetings providing the opportunity to present and share results.

7.6. Conclusions

The redevelopment of New Covent Garden Market forms part of one of the largest urban regeneration projects in London's history, and has presented a unique opportunity to undertake deposit modelling at the macro-landscape scale. The aim of the deposit modelling was to map the subsurface topography and characterise the key deposits, with the objective of identifying areas of potential as a guide for directing further geoarchaeological and archaeological works in advance of construction.

The deposit modelling identified a series of high and low areas across the site, representing the undulating fossilised floodplain of the Late Pleistocene cold-climate braided river system. Lower areas were infilled with Holocene alluvium and peat, whilst the intervening islands of dry land and the marginal ground adjacent to the low-lying wetland or channel features are likely to have proved attractive to prehistoric communities for a range of activities. The deposit model was therefore successful in identifying suitable areas for further geoarchaeological and archaeological investigation.

The model was reliant on existing geological information, but benefitted from collaboration with other archaeological organisations through the Battersea Channel Project. This provided the opportunity to include SI data from adjacent sites within the Nine Elms redevelopment area. The model will be updated with the results of subsequent archaeological and geoarchaeological investigations scheduled to take place in stages over the coming years.

Acknowledgements

Thanks are due to VINCI St. Modwen (VSM) for commissioning and funding the works at NCGM, to Mark Stevenson at Historic England for organising the Battersea Channel Project, and of course to fellow members of the BCP Forum for their continued cooperation and enthusiasm.

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Constructing a geoarchaeological deposit model: New Covent Garden

Assess pre-existing data

- British Geological Survey borehole records
- Geotechnical borehole and test pit records
- Geoarchaeological/geotechnical records shared as part of the Battersea Channel Project

Develop rationale for model construction and key aims and objectives

- To model the subsurface topography and key stratigraphic units, particularly the location of gravel islands and low-lying wetland areas
- To guide further geoarchaeological and archaeological works, including the positioning of trial trenches

Can the deposit model be constructed using pre-existing data?

Yes

Commission further ground investigations, including:

- Further purposive borehole transect to sample palaeoenvironmentally significant deposits

Construct deposit model comprising of one or more of the following:

- Digital elevation models showing key surfaces and unit thickness plots
- Representative cross-sections

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- Model evaluated during further trenching and data fed into the wider Battersea Channel Project so under continual scrutiny by both the Wessex team and other project members

Revise final product

Deposit model integrated with palaeoenvironmental and archaeological data and reports drafted

Archive and reuse

Data and reports archived for the individual site and as part of the wider Battersea Channel Project

8. An archaeological deposit model of Site A, London Gateway Port development

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Abstract

During 2008 an ecological compensation scheme as part of the DP World London Gateway Port development, adjacent to the Thames estuary near Stanford-le-Hope, Essex, required the creation of an intertidal habitat, through a reduction of the land surface by approximately 1m and re-alignment and breach of the existing sea wall in an area of historically reclaimed salt marsh. This compensation area was referred to as Site A and later renamed Stanford Wharf Nature Reserve. Deposit modelling was undertaken across Site A, using gouge coring and resistivity transects to define the interface of the Holocene-Pleistocene deposits and to characterise the sedimentary architecture of the postglacial sequence. A gradiometer survey was also undertaken as part of the deposit modelling programme to identify archaeological remains within the upper 1m of the sediment sequence, which was the limit of the impact depth from ground reduction. The deposit model allowed a geoarchaeological zonation of the site, with Zone 1 interpreted as a buried river terrace containing the potential for deeply stratified and well-preserved archaeological remains. Evaluation trenching targeted key archaeological features across the site to characterise the depths and potential of any recorded archaeological and palaeoenvironmental remains. This approach of targeted evaluation, informed by deposit modelling, allowed for a reduced trenching strategy compared to a standard blanket evaluation

Comparative data table of this deposit model	
Deposit model location	Lower Thames Valley, Stanford-le-Hope, Essex
Depositional environment	Estuarine
Size of deposit model	44Ha
Data collection strategies	Electrical resistivity survey, hand gouge core, lidar data, gradiometer survey and aerial photographs
Position in the archaeological process	Before evaluation trenching
Reason for deposit model construction	Ecological compensation scheme required as a result of reclamation for a large development. The compensation scheme required the land surface to be reduced by approximately 1m and managed re-alignment and breach of the existing sea wall over 44Ha to create intertidal habitat
Archaeological question	To investigate whether archaeological remains survived within the impact zone of the 1m land reduction across the development area
Software and modelling process	ArcGIS, hand drawn sections and Res2Dinv
Outputs from the deposit model	Geomorphic zonation of the development area and assessment of archaeological potential

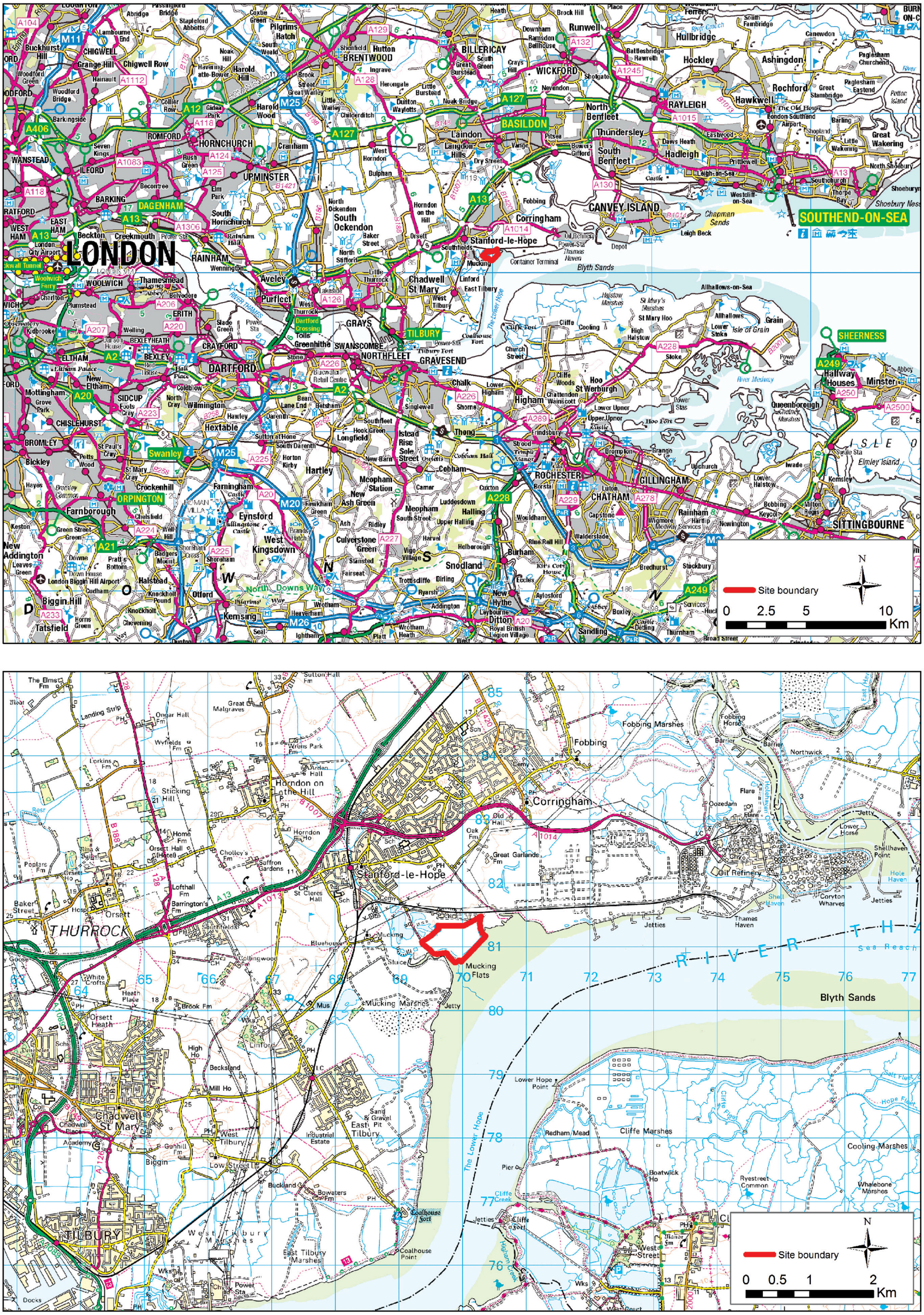


Figure 8.1: The location of Site A on the north bank of the Lower Thames Estuary

process of an agreed percentage area. In turn, this allowed the archaeological process to proceed quickly from evaluation into excavation mitigation and facilitated post-excavation analysis of the sequences, providing a rich archaeological narrative.

8.1. Introduction

The development of DP World London Gateway Port development, adjacent to the Thames Estuary near Stanford-le-Hope, Essex, was a major infrastructure project requiring a complex package of mitigation responses for historic environment assets, including palaeoenvironmental remains. The development was spread across several sites within the locality, with the archaeological mitigation for each site undertaken within a larger, overarching framework. One of the most important components in the overarching framework was the development of a site-wide deposit model (Bates *et al* 2012), which provided the context for further stages of work. The archaeological project was run by Oxford Archaeology, who embedded a geoarchaeologist within the site team to oversee the archaeological programme across a number of sites, many of which (such as Site A) had deep intertidal sediment sequences.

The development required the designation of a parcel of land within the lower Thames Estuary to be used as ecological compensation for the loss of intertidal habitat within the wider scheme. Site A (Figure 8.1; NGR 569900, 181100) was selected for this purpose: an area of previously reclaimed intertidal habitat used as arable farmland. The ecological compensation scheme proposed breaching a sea wall and lowering the contemporary ground surface by approximately 1m in order to return this area to saltmarsh. As Site A lay outside of the boundary of the original deposit model (Bates *et al* 2012) it was proposed to construct a small-scale model, principally to understand the character of the interface between the Pleistocene sands and gravels and the finer-grained postglacial (Holocene) sedimentary sequence at Site A. Prior to undertaking field investigations, British Geological Survey (BGS) mapping suggested that Site A was blanketed by a deep sequence of fine-grained alluvium (undifferentiated). Therefore, it was assumed that the approximate 1m reduction in land surface would only impact upon relatively recent intertidal silts and clays with low archaeological potential. Deposit modelling was undertaken in November 2008 followed by archaeological evaluation and mitigation in 2009.

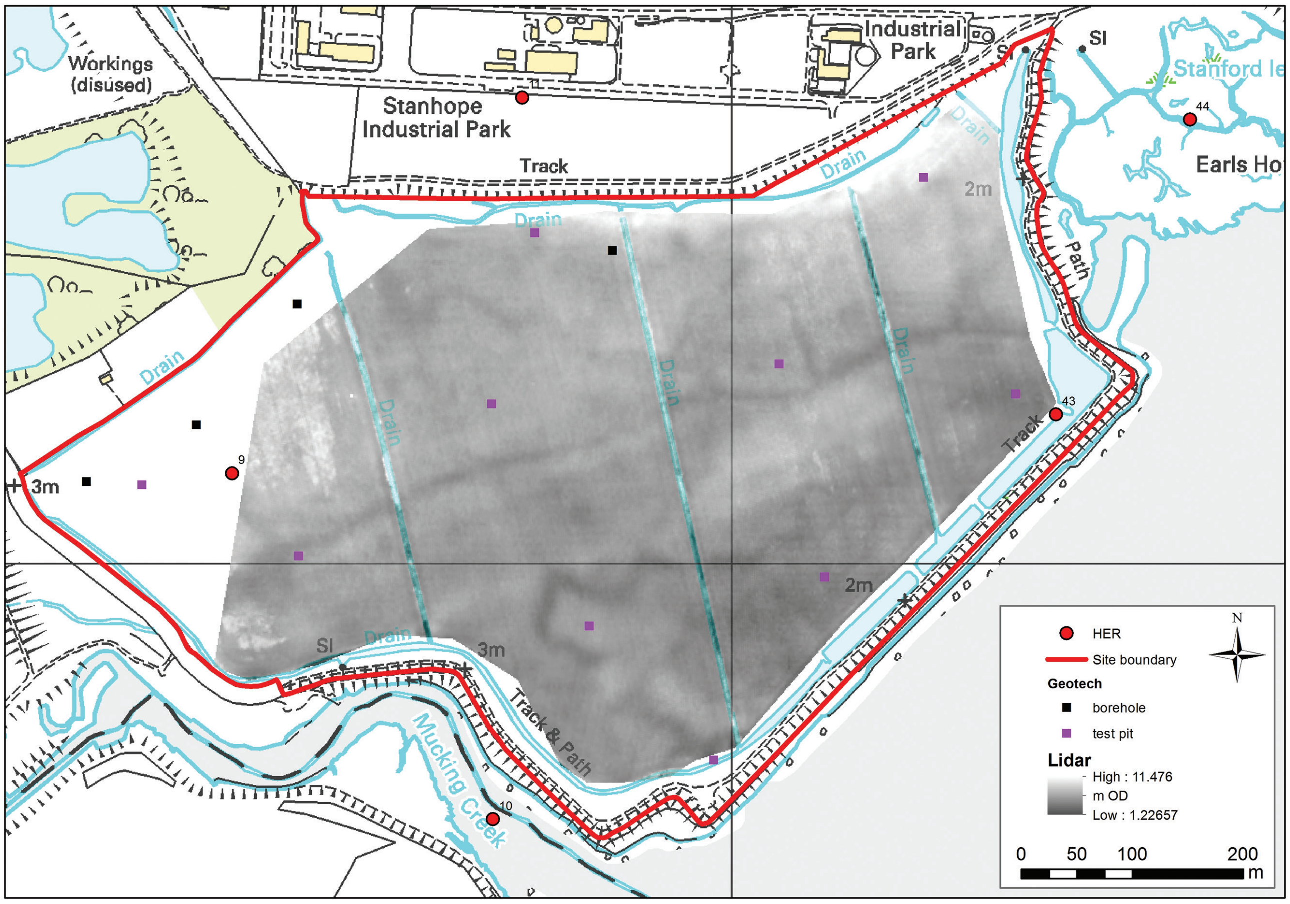


Figure 8.2: Existing lidar data and geotechnical test pits

8.2. Objectives

Given the limited understanding of the mapped geology of Site A, existing geotechnical and remote-sensing data were collected. As described previously, the BGS 1:50,000 map sheet recorded the site as an area of undifferentiated alluvium; however, the lidar data revealed some topographic variability, which suggested subsurface geomorphological variations (Figure 8.2). The existing geotechnical borehole data indicated that the contact between the Holocene alluvium and underlying Pleistocene sands and gravels might vary across Site A. In addition, the Essex Historic Environment Record (HER) indicated the presence of archaeological remains, including a possible Romano-British well, which was recorded in 1967 (SMR 5188, Point 9, Figure 8.2). The geotechnical data was considered to be of variable quality for the purposes of archaeological assessment and was unevenly distributed; therefore, it was decided to undertake purposive geoarchaeological fieldwork to inform the construction of a deposit model.

The objectives for the Site A deposit model were to:

- Provide an understanding of the interface between the Pleistocene and Holocene sediments;
- Identify any variations in sediment composition that could be related to areas of high palaeoenvironmental, ecofactual and archaeological potential;
- Produce a geomorphological map that zoned the site in relation to its archaeological potential;
- Use the deposit model to inform evaluation strategies for trial trenching and other mitigation options.

If, as described by the BGS, Site A comprised a deep alluvial sequence, a watching brief would be the most cost-effective mitigation strategy. In such circumstances, it could be predicted that the archaeological potential within the top 1m of the sediment stack (the proposed depth of the surface reduction) would be low. Moreover, even if archaeological remains did survive within this zone, the difficulty of predicting their location with any degree of confidence would favour a continuous watching brief during ground disturbance. In contrast, if areas of elevated subsurface topography were identified beneath the alluvium, such as gravel islands or terrace remnants, these would have a higher archaeological potential, reflecting previously drier areas more suitable for habitation/exploitation at the intertidal edge and would require more extensive evaluation. Consequently, an understanding of sediment stratigraphy at Site A was

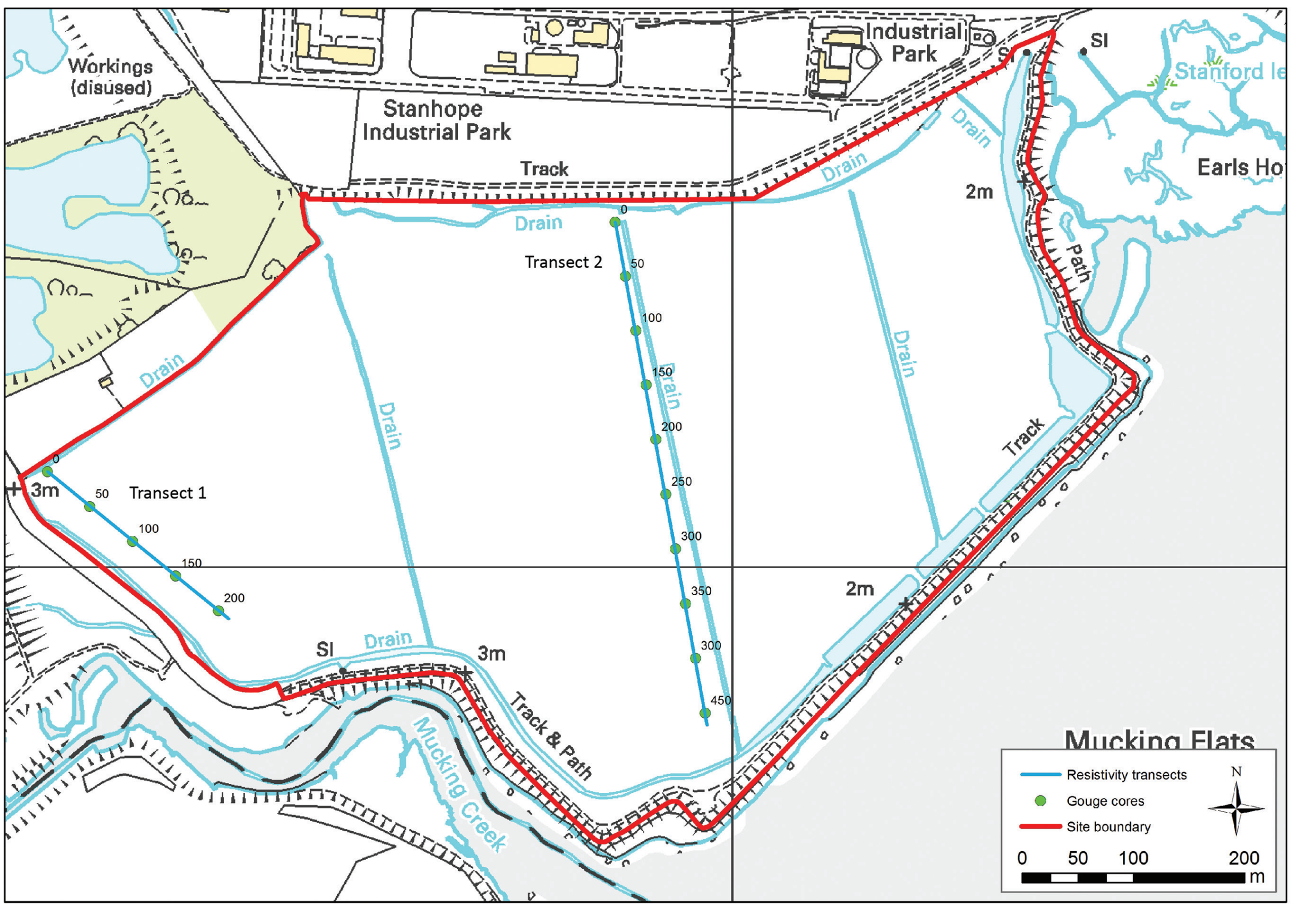


Figure 8.3: Resistivity transect and gouge auger locations

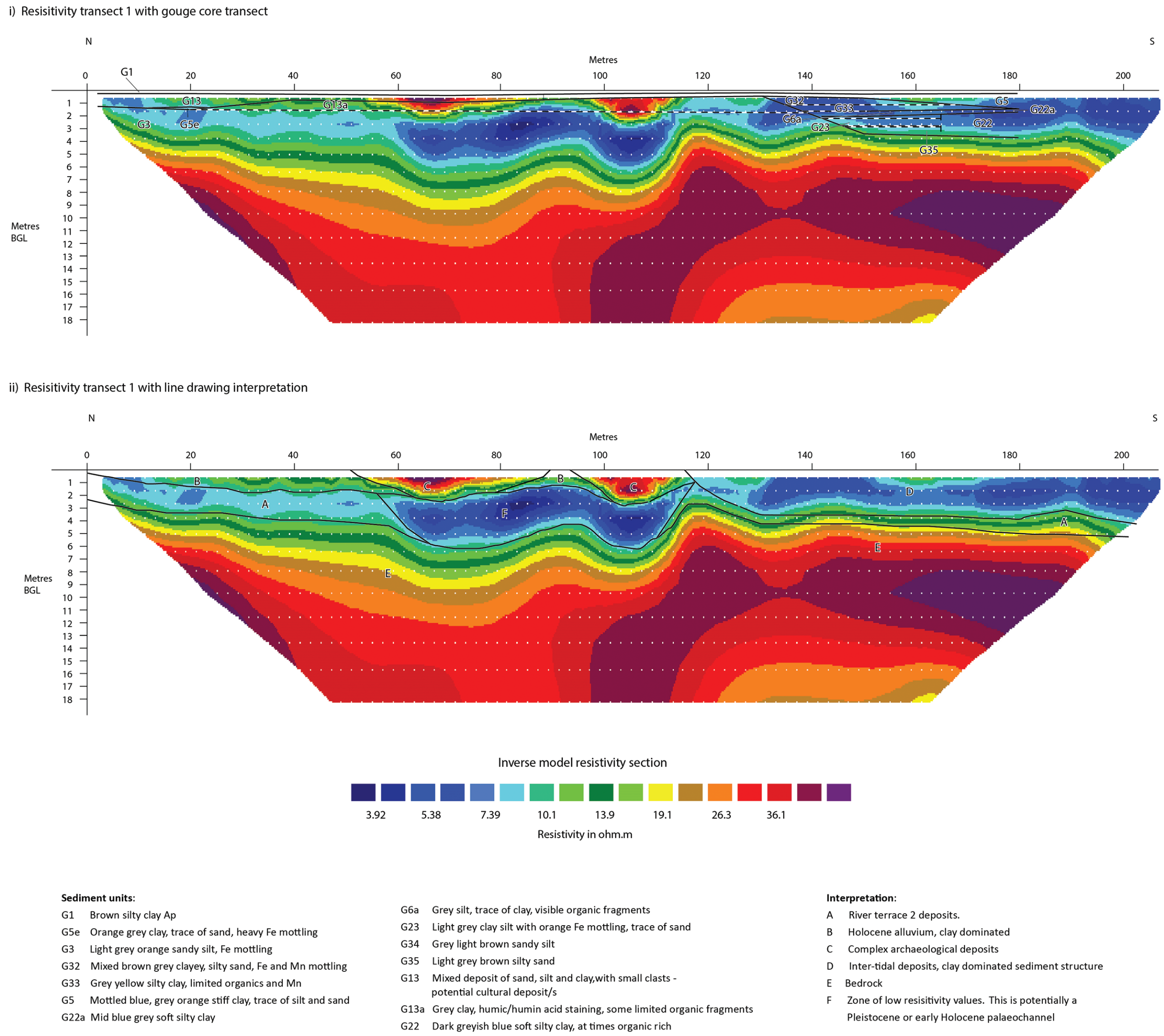


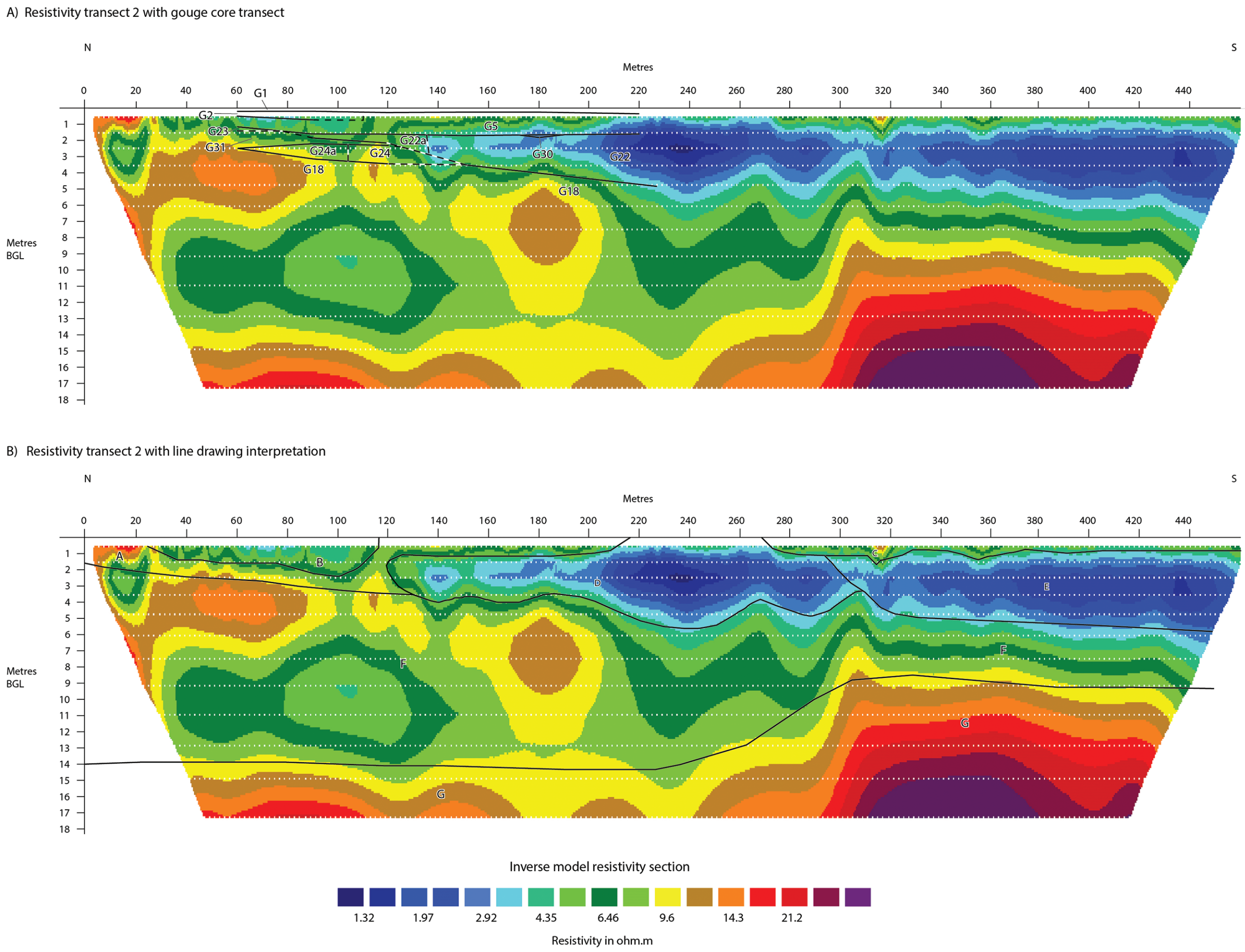
Figure 8.4: Electrical resistivity Transect 1 results, with gouge core data and interpretation. A clear difference is visible between the north and south ends of the transect. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

deemed to be essential for defining intra-site variations in archaeological potential.

8.3. Methodology

The purposive fieldwork that was undertaken to inform the construction of the deposit model involved the capture of data along two electrical resistivity transects, orientated broadly north-west to south-east. The presence of higher ground to the north of the site and of intertidal deposits to the south, within the general framework of the Thames terrace sequence (Bridgland 1994), meant that the key trends in the interface between Pleistocene and Holocene sediments would be identified from a broadly north-south transect. Transect 1 extended for 210m and Transect 2 extended for 460m (Figure 8.3). Hand gouge augering was undertaken at 50m intervals along the resistivity transects, both to investigate the nature of the Holocene sediment stack and to aid interpretation of the electrical resistivity data.

The electrical resistivity data was captured using an Iris Syscal pro 72 system with an internal switching unit using the Wenner-Schlumberger collection array. A 2m electrode spacing was used, allowing a depth penetration of *c* 15m. The IRIS Syscal was programmed using Electre II, with data downloaded into PROSYS II before being imported into Res2Dinv for processing, using a Robust Inversion method. The sediment stratigraphy from the gouge cores was recorded in the field using standard geological terminology (for example, Jones *et al* 1999).



Sediment units:

G1 Brown silty clay Ap
G2 Stiff brown grey silty clay
G23 Light grey clayey silt, Fe mottling and organics
G31 Dark grey clayey silt, with ltd organics
G5 Mottled blue, grey orange stiff clay, trace of silt and sand
G18 Undifferentiated head (brown silty clay, with small clasts)
G22a Mid blue grey soft silty organic rich clay
G24a Stiff brown grey silty clay, abundant organics
G29 Light grey silty clay with organics
G24 Mid brown grey silty clay
G22 Dark greyish blue soft organic rich silty clay
G30 Mixed light grey dark grey silty clay

Interpretation:

A Higher resistance Holocene alluvium
B Lower resistance Holocene alluvium
C Higher resistance Holocene alluvium
D Palaeochannel
E Inter tidal deposits
F Undifferentiated Head deposit
G Bedrock

Figure 8.5: Electrical resistivity Transect 2 results, with gouge core data and interpretation. As with Figure 8.4, there is a clear difference visible between the north and south ends of the transect. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

The sediment data was hand drawn into sections and was integrated with the processed electrical resistivity transects in Adobe Illustrator.

Due to a proposed approximate 1m depth of ground disturbance, an archaeological gradiometer survey was used to identify any shallow archaeological features. As well as being able to identify archaeological remains, the gradiometer data could also be used to define variations in sediment composition and to aid the definition of geomorphological zones across the site. The gradiometer survey was undertaken using a Bartington Grad 601-2 gradiometer; all data was downloaded and processed in 'Archaeosurveyeur'. All subsequent data integration was conducted within ArcGIS, allowing integration of multiple data sources. These combined datasets were interpreted to produce a geomorphological zonation map that highlighted the variable archaeological potential of the site.

The proposed groundworks at Site A identified quickly the need for a deposit model to aid the definition of the archaeological potential. Therefore, the deposit model was created prior to any groundworks taking place. Once the deposit model had informed assessment of archaeological potential in each discrete geomorphic zone, a programme of limited evaluation trenching was instigated. This was followed by a programme of more extensive stripping, which was integrated into the construction schedule, allowing archaeological mitigation and construction groundworks to occur in tandem.

8.4. Interpretation

It became apparent from an early stage of fieldwork that the subsurface topography and depositional history of Site A varied significantly. The key trends in the resistivity transects and gouge core data are described below. The results of this work were used to construct a geomorphological zonation of Site A, which was directly linked to archaeological potential.

Resistivity transects

Transect 1 (Figure 8.4) traversed the north-west part of Site A. It revealed a very shallow alluvium (Unit G1, *c* 0.2m) at its northern end, overlying sands and gravels. Further south, between 10m and 120m from the northern end of Transect 1, deposits dominated by a mixture of sand, silt and clay were recorded (eg Units G13 and G13a: grey clay containing organic matter); these deposits overlaid sand and gravels interpreted as Pleistocene river terrace deposits (G3). Units G13 and G13a were initially interpreted as possible cultural horizons. They were defined during subsequent excavations as components of a complex sequence of archaeological deposits, some of which had been partially reworked by tidal action; the organic content in these units indicated high potential for the preservation of both ecofactual and palaeoenvironmental remains.

Within Transect 1, Unit C was interpreted as a sequence of archaeological deposits. Unit B was interpreted as alluvium, although excavation demonstrated that this zone also included complex stratified archaeological deposits. Unit D was interpreted as a palaeochannel/inter-tidal alluvium, overlying sand and gravel (Unit A) at *c* 6m BGL. From a geoarchaeological perspective, Unit F is also of interest since it was interpreted as a fine-grained deposit within the terrace sands and gravels and may correspond to a Pleistocene palaeochannel or brickearth deposit; it was noted that both of the latter had palaeoenvironmental potential, but this anomaly was not investigated further during the excavation.

Transect 2 (Figure 8.5) revealed a broadly similar pattern to that recorded in Transect 1, although the Holocene sediments in this transect rested on underlying Pleistocene Head deposits. The undifferentiated Head deposit overlay a landform that may probably be correlated with the River Terrace deposit identified in Transect 1. Above the Pleistocene Head the Holocene alluvium was observed to increase gradually in thickness

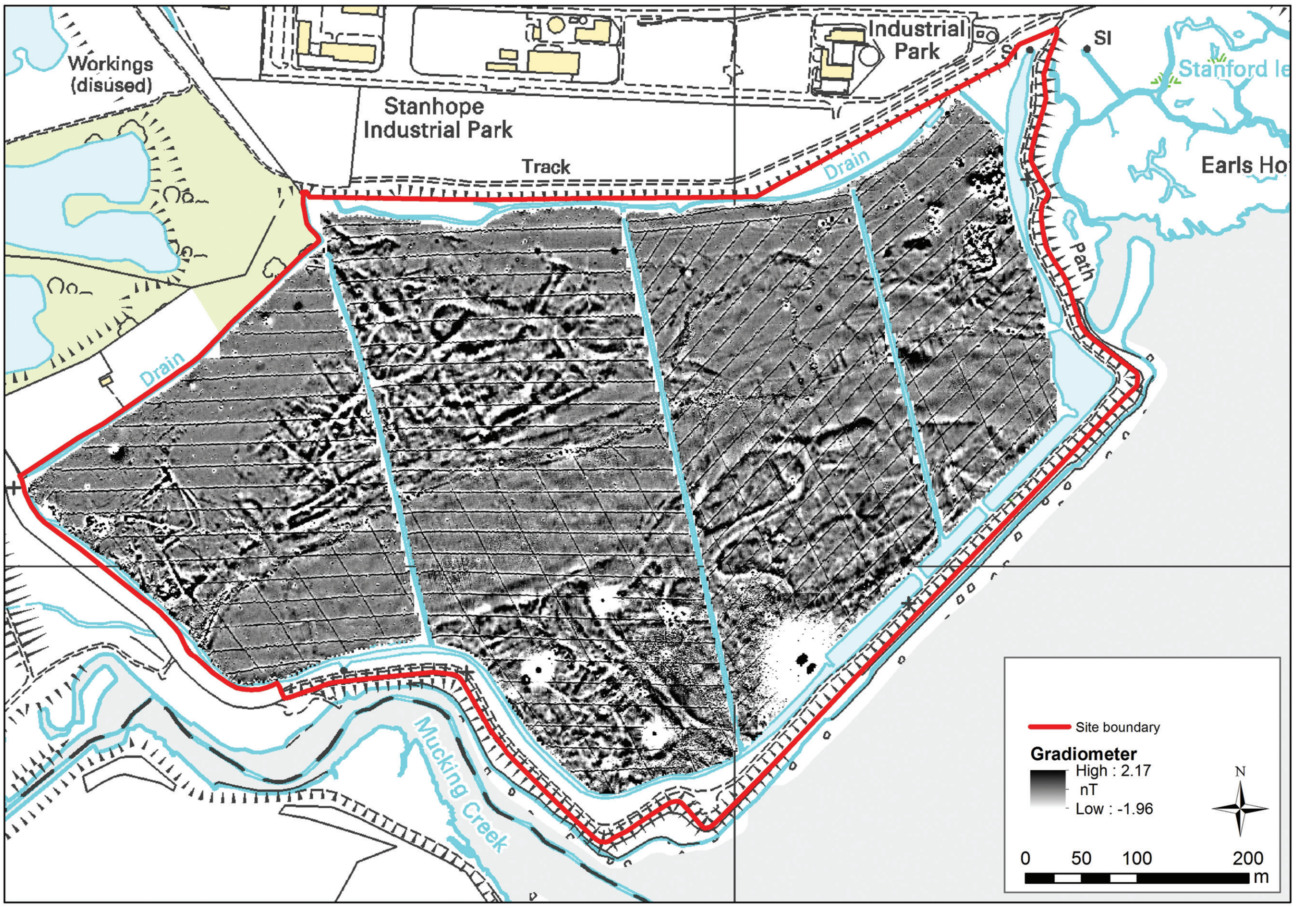


Figure 8.6: The gradiometer results, revealing a wealth of features to the north end of the site. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

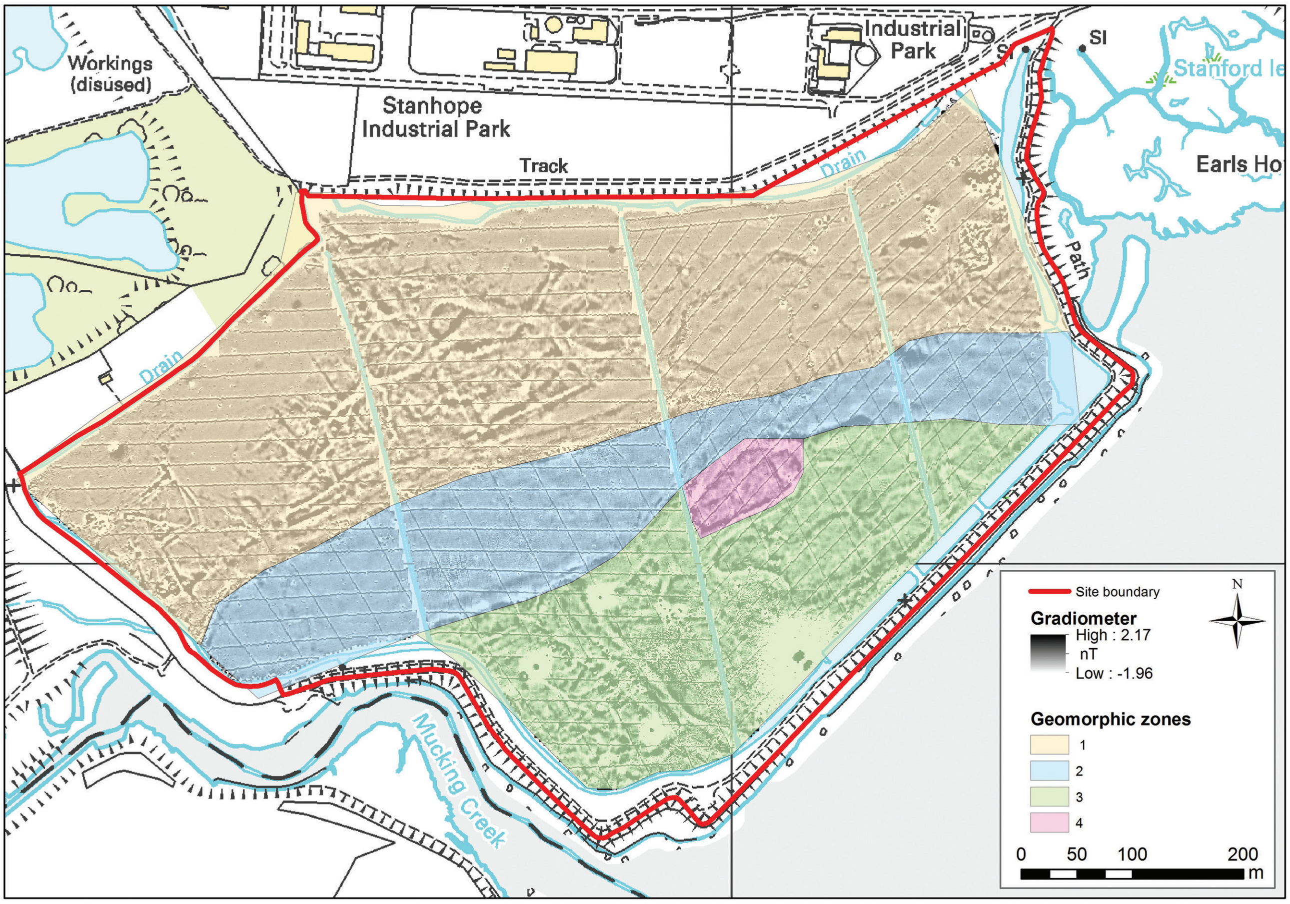


Figure 8.7: Geomorphic zonation of the site, with a description of depth of Holocene deposits and archaeological potential. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

from a depth of *c* 0.2m at the north of the transect to a depth of *c* 3.5m at 120m along the transect. The sediment sequence above this Pleistocene Head interface varied in comparison to Transect 1, with units such as G22 and G22a being recorded as blue-grey silty clays with organics and G24 and G24a as brown-grey silty clays. Across this transect the archaeological potential was more difficult to define at the northern end, but again the shallow depth of Holocene deposits above Pleistocene sediments suggested a high potential. The interpretation of sediment units from the resistivity transects defined Units A and B as Holocene alluvium until about 120m, Unit D as a central palaeochannel with a fill sequence of *c* 5m and Unit E as the intertidal alluvial deposits to the south.

Both transects demonstrated that the northern edge of the site was characterised by an incised river terrace deposit, consisting of both sands and gravels, together with undifferentiated Head. These terrace deposits were overlain by a shallow covering of alluvium at the northern end of the site. This alluvium slowly increased in depth southwards, in part associated with a large palaeochannel that traversed the site on a broadly east-west alignment. To the south of the palaeochannel, intertidal alluvial deposits of considerable depth (*c* 6–8m BGL) were recorded. The area of higher terrace to the north of the central palaeochannel, buried by a shallow covering of alluvium, was defined as a zone of very high archaeological potential.

Gradiometer survey

The gradiometer survey complemented the results of the deposit model and clearly defined the palaeochannel traversing the site. To the north of the site, the gradiometer also defined several significant archaeological structures, including an enclosure, multiple widespread magnetic deposits, and a variety of other features (Figure 8.6).

Geomorphic zones

On the basis of fieldwork and deposit modelling, the site was divided into four distinct geomorphic zones, each providing an understanding of sediment architecture, sequence stratigraphy and archaeological and palaeoenvironmental potential (Figure 8.7). This was displayed within a 2-dimensional plan based format, although knowledge of the depth and architecture of the underlying sequence from the resistivity and gouge coring effectively created a 3-dimensional deposit model. The key zones were:

- Zone 1: elevated fluvial terrace covered by inorganic, minerogenic alluvium, with significant potential for the preservation of archaeological features beneath alluvium. The interface between Holocene alluvial and Pleistocene terrace deposits was observed to lie within the 1m impact depth of the proposed ground disturbance; there was a strong likelihood, therefore, that archaeological features would be impacted by development;
- Zone 2: palaeochannel incised into terrace, with an interface between Holocene alluvium and Pleistocene deposits at *c* 6m BGL. The archaeological potential was difficult to define, but the palaeochannel deposits below impact depth had the potential to include significant palaeoenvironmental and ecofactual remains. The margins of the channel may also have corresponded to an area of preferential human activity at the wetland-dryland interface;
- Zone 3: Holocene estuarine intertidal sediments, overlying Pleistocene deposits at *c* 7m+ BGL. These had low archaeological potential within the 1m impact depth of the proposed ground disturbance.
- Zone 4: a slightly elevated area, interpreted as possibly a gravel island with potential for the presence of archaeological features. The depth of the interface between Holocene and Pleistocene deposits was unknown at the point of deposit modelling; it was covered by an unknown depth of alluvium, as it was located outside of the resistivity transects and was only defined through the gradiometer survey. On the basis of knowledge from the deposit model, the archaeological potential within the 1m impact depth of the proposed ground disturbance was judged as moderate, and was established by later evaluation trenching.

8.5. Investigations following development of the deposit model

Based upon the high level of understanding derived from the deposit model, a targeted evaluation trenching programme was implemented (Figure 8.8). Trenches were located with the aims of investigating discrete features to assess their archaeological potential and of testing the predictions of the deposit model regarding the depth and character of the sedimentary sequences and the presence of associated archaeological horizons. Such a focused approach confers a number of advantages. First, areas of high archaeological potential can be targeted, giving

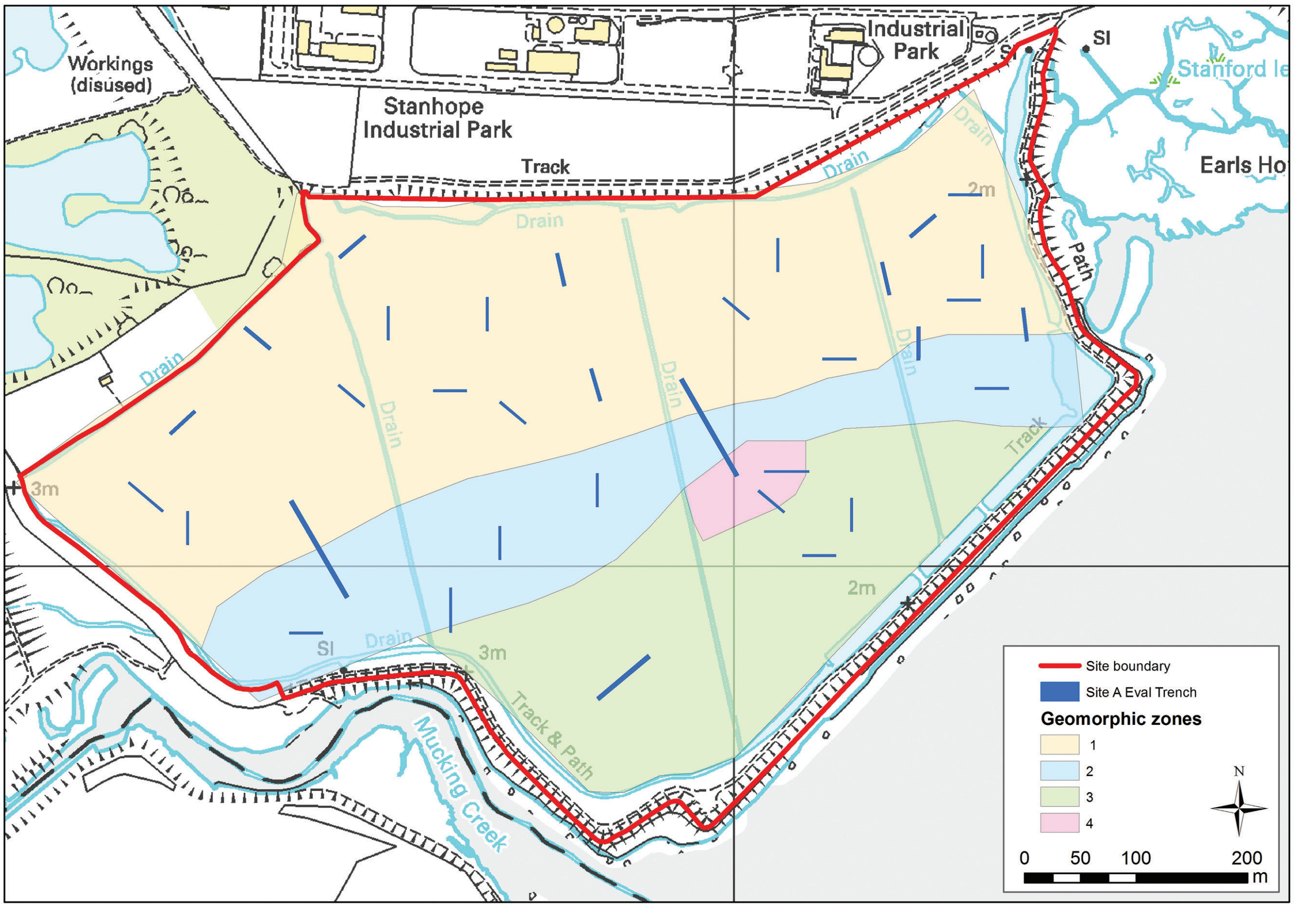


Figure 8.8: The targeted evaluation trenching programme design, using 34 evaluation trenches to evaluate the 44Ha site. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

a truer representation of the archaeology present and the resources required for any subsequent mitigation phases. Secondly, some trenches can test the areas of lower predicted archaeological potential: a task that can be undertaken with confidence at a lower trenching density. Thirdly, the approach can reduce a lengthy and at times costly evaluation programme using blanket sampling strategies (eg 5% evaluation trenching). By using a targeted evaluation programme, the trenching can focus more effectively upon the nature and potential of the archaeological remains, and less upon presence or absence.

The results of this deposit model, combined with the evaluation trenching results, provided a clear picture of complex archaeological and sediment sequences within some areas of the development site. The results demonstrated an increasing depth of sediment across Zone 1, together with an increasing depth and complexity of archaeological deposits. The evaluation trenching also identified a spatially extensive sequence of Holocene units across Zone 1, which were assigned a series of geoarchaeological codes prefixed by the letter G. These G codes denoted sediment units in the excavation area that were diachronous in their formation. Numbering these sediment units as conventional archaeological contexts could cause conflicts in a Harris Matrix, as many of these units formed over protracted time periods. For example, G4 represented an early Holocene palaeosol in Zone 1 that was associated with Bronze Age and earlier activity; this was stratified above G3, a late Pleistocene/early Holocene sand-dominated sediment. Likewise, G5 corresponds to a blue-grey silty clay alluvium, which was first recorded in the southern end of Zone. With rising sea levels in the mid-Holocene, however, G5 encroached northwards; the timing of its formation thus varied significantly across the site. The application of 'G' prefixes to context codes represents an attempt to overcome the problem of age relationships by attributing unique alpha-numeric codes to Holocene sediment units extending widely across the site, while at the same time applying unique context numbers to occurrences of these sediment units in individual evaluation trenches.

Following evaluation trenching, a full archaeological surface strip was integrated into the construction schedule. Zone 1 revealed an extremely well-preserved land surface above river terrace deposits, including extensive, locally complex archaeological remains. Zones, 2, 3 and 4 were stripped under archaeological watching brief conditions and in contrast revealed no significant archaeological remains.

The deposit sequence of Zone 1, overlying the late Pleistocene and early Holocene land-surface, included an extensive and well-preserved Bronze Age palaeosol and, deeply stratified sequences of cultural deposits relating to Iron Age and Roman activity; these later deposits were often interspersed by marine incursions denoted by estuarine alluvium. Anthrosols created from extensive 'redhill' deposits (red, burnt material generated during salt production) and interleaved with further stratified archaeological remains, developed during the Romano-British periods. All of the archaeological deposits that were recorded at Site A were covered by the thin deposit of alluvium that crept over the higher, northern edge of the site in the late Roman or early Post-Roman period, sealing and preserving a rich archive of activity up to the 5th century AD (Figure 8.9).

The Iron Age and Romano-British activities at the site were investigated during the mitigation excavation. They revealed a Late Romano-British saltern with hearth (AD 200–AD 410); a later Romano-British enclosure incorporating a roundhouse defined by bedding trenches preserving wooden stakes (AD 200–AD 410); extensive redhill deposits and associated infrastructure for salt production; and evidence for Late Roman fish paste production (sample <1160>) (Biddulph *et al* 2012). Due to the extensive and locally complex nature of the Romano-British and Iron Age remains, these phases were heavily represented in the site archive. Earlier archaeological remains, however, such as those relating to Bronze Age settlement could only be investigated through window–sampling as they were located beneath later phases of activity. All of these excavations followed the principle of attributing alpha-numeric G codes to the major lithostratigraphic units, as described above, attempting thereby to harmonise sediment descriptions across this complex landscape zone.

The method of excavation provided an opportunity for detailed and extensive geoarchaeological sampling using monolith tins and bulk samples. Multiple samples were obtained for post-excavation analysis, with the focus upon understanding the cultural deposits, anthrosols and palaeosols by a combination of soil micromorphology and the study of diatoms, pollen, charred plant remains, waterlogged plant remains and foraminifera. By combining these analyses, a rich narrative was generated for the occupation and exploitation of this site at the wetland-dryland interface. In the post-excavation process, the deposit model was updated with data obtained by excavation. The deposit model provided the framework for the contextualisation of the archaeological remains discovered and for the detailed post-excavation analysis of artefacts and samples. The post-excavation strategy was devised with the aim of facilitating site-wide palaeoenvironmental and sediment investigations by the analysis of localised archaeological sequences and features. In all cases the deposit model was central for understanding the depositional environment of the samples and their archaeological position within the overall narrative of site evolution. As the deposit model was firmly embedded into the archaeological process, the end product can be considered to have created a holistic understanding of the sediment and archaeological sequences. In this sense the deposit model was central

Figure 8.9: Some of the archaeological sequences and remains revealed on the western side of zone 1, showing (top plate) palaeosol and land surface, (middle plate) one of many locally variable complex deposit sequences and (bottom plate) aerial shot of the mitigation excavation in progress. Reproduced with permission of Oxford Archaeology (© Oxford Archaeology)

to the archaeological process from inception through to publication.

8.6. Conclusions

The DP World London Gateway deposit model generated multiple benefits for the client and enhanced significantly our understanding of the archaeological remains at Site A. It highlights the benefits for archaeologists in using such methodological approaches to identify areas of both high and low archaeological potential within deeply stratified (>1m) and complex geomorphological and sedimentary environments. The deposit model also allowed resources to be efficiently targeted and enabled the archaeological programme to be firmly embedded within the construction schedule. The evaluation trenching demonstrated that in such environments, following the application of a deposit model, a blanket evaluation trenching strategy (for example of 5%) is not suitable. The subsequent excavation provided a rich archive of samples for detailed archaeological, palaeoenvironmental and geoarchaeological analysis.

The deposit model is archived within a GIS environment and the shapefiles and raster files are accessible for future researchers to use. Oxford Archaeology produced very promptly a monograph exploring the results of deposit modelling and other site investigations (Biddulph *et al* 2012), creating thereby a lasting legacy. A further important outcome was the use of deposit modelling as a training and education vehicle for project staff. Not all of the staff who were involved with the project were used to working within such mitigation frameworks or in such sedimentary environments. The application of 'G' codes represented an attempt to integrate geoarchaeological investigations of the major lithostratigraphic units with traditional context recording systems. Since the application of new recording systems and new methodological approaches to site investigation can take a while to be understood before they become normal best practice, it is essential for the geoarchaeologist undertaking deposit modelling to be embedded within the project team and to provide a geomorphological context for the mitigation process. It is vital to explain the value of deposit modelling in the process of site investigation and how the results need to be firmly embedded in the site archive. It might seem obvious, but it is important to communicate why samples are required from the excavation and how the full integration of geoarchaeological and archaeological data will provide a richer and more comprehensive site narrative.

In more general terms, although deposit modelling can increase the capacity of archaeologists to uncover complex and often exceptionally well-preserved archaeological remains, the surviving remains, once disturbed, will often degrade through increased oxidation and the lowering of water-tables. This presents a major challenge to the historic environment sector, as there is clearly a need to maximise data recovery once such sites are uncovered. In an era of tightening budgets, this issue needs to be considered not only during the design of archaeological programmes but also during communications with developers, ensuring thereby the design of cost-effective investigation strategies that can maximise understanding of the archaeological and environmental resource.

Acknowledgements

Oxford Archaeology is thanked for allowing the publication of some of the figures from the original site investigation. DP World London Gateway is also thanked for allowing publication of this data and funding of the original project. Special thanks to Martin Bates, Liz Stafford and Gill Andrews for their help and support throughout the lifetime of the project and the publication of this chapter.

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Constructing a geoarchaeological deposit model: Site A

↓

Develop rationale for model construction and key aims and objectives

1. Understand Holocene sediment sequences
2. Define archaeological potential
3. Recognise different depositional environments

↓

Can the deposit model be constructed using pre-existing data?

No

↓

Assess pre-existing data

No archaeological grey literature
Limited prexisting boreholes
BGS surficial 1:50,000 sheet consulted
HER added to GIS

↓

Construct deposit model comprising of one or more of the following:

Commission further ground investigation:

- Gouge coring combined with resistivity transects
- Gradiometer survey

↓

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

Targeted evaluation trenching programme
Extensive surface strip and large scale archaeological mitigation excavation
Detailed post excavation analysis

↓

Revise final product

After initial deposit model the site excavation revealed a much greater complexity of site sediment sequences. Deposit model used and updated throughout the archaeological fieldwork and post excavation analysis phases.

↓

Archive and reuse

Data and reports archived with Oxford Archaeology and Essex HER. Monograph published in 2012.

9. Post-Medieval marsh and reclamation activity at Sadds Wharf, Maldon, Essex

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Abstract

An evaluation and borehole survey was undertaken ahead of development at Sadds Wharf, Station Road, Maldon, Essex. The development site lay adjacent to the river Chelmer and close to its confluence with the river Blackwater, where they join to form the Blackwater estuary. British Geological Survey (BGS) mapping indicated that the site was situated upon Pleistocene river terrace sands and gravels and silt and clay alluvium, the latter formed in an intertidal, salt marsh environment. Ground investigations included a borehole survey aimed at assessing the deeper fine-grained alluvial sediments and associated organic remains, with the data also used to construct a deposit model. The borehole records revealed varying levels of episodic reclamation across the site. Pollen samples obtained from the alluvial silts indicated an absence of pollen, strongly suggesting that the deposits were degraded through prolonged exposure to oxygen. This affirms the documentary and cartographic data for the Post-Medieval environment, which remained marshland until the 19th century. The borehole survey also revealed an absence of alluvial silts in some areas of the site and confirmed the known level of the rising gravel deposits. This supports the BGS mapping of the area and suggests that gravel islands were present in the intertidal zone and a prominent feature of the earlier landscape. The subsequent trial trench evaluation successfully identified and characterised a Post-Medieval timber causeway running between the gravel islands, across an area of alluvium. The study also confirmed that the marsh was formerly higher, wetter and more difficult to navigate than at the present day.

Comparative data table of this deposit model	
Deposit model location	Maldon, UK (NGR: 585460 207310)
Depositional environment	Intertidal zone of the rivers Chelmer and Blackwater
Size of deposit model	The deposit model covered the area of development *c* 1.80Ha
Data collection strategies	Cable percussive boreholes, followed by trial trench evaluation
Position in the archaeological process	Initial ground investigation prior to trial trenching
Reason for deposit model construction	To model, assess and analyse the deeper alluvial sediments and any associated organic deposits, and to map the extent of the known reclamation activity at the site
Archaeological question	Define the extent of the Post-Medieval reclamation and consolidation activity at the site
Software and modelling process	The data was sorted in Excel, and mapped to a stratigraphic sediment model in AutoCad. Subsequent drawings were also produced using AutoCad
Outputs from the deposit model	A series of representative cross-sections and location plans

9.1. Introduction

An archaeological evaluation and geoarchaeological investigation was undertaken at Sadds Wharf, Station Road, Maldon, Essex (NGR: 585460 207310), in advance of the proposed development of the site (Figure 9.1). The development was located adjacent to the river Chelmer and close to its confluence with the river Blackwater. British Geological Survey (BGS) mapping indicated that the site was situated upon Pleistocene river terrace sands and gravels and silt and clay alluvium, the latter formed in an intertidal, salt marsh environment. The underlying bedrock geology comprised London Clay. A deposit model was requested by the Local Planning Authority (LPA) to map the full extent of the intertidal alluvial deposits and to assess their relationship to any archaeological assets that might survive within the proposed development area.

Given the logistical issues surrounding the development, which included a large remediation project, it was agreed that a borehole survey would be undertaken prior to archaeological trial trenching. The deposits were to be sampled in transects using a cable percussion borehole rig with sediment retained for later palaeoenvironmental assessment. Analysis of a number of proxy indicators would enable reconstruction of the local palaeoenvironments. The borehole transects would be used, therefore to elucidate site formation processes and to understand changes in the geomorphology and hydrology of the site. The deposit modelling was undertaken by Britannia Archaeology Ltd in consultation with Dr Steve Boreham (University of Cambridge) and Maria Medlycott (Essex County Council).

9.2. Aims and objectives

Deposit modelling was undertaken to provide an assessment of the geoarchaeological potential of the site and, if possible, to correlate visible topographic features with the buried sedimentary sequence. In addition to recording the general stratigraphy, a specific aim of the borehole survey was to target and sample organic-rich, fossiliferous sediments and to characterise associated minerogenic interfaces. The subsequent archaeological

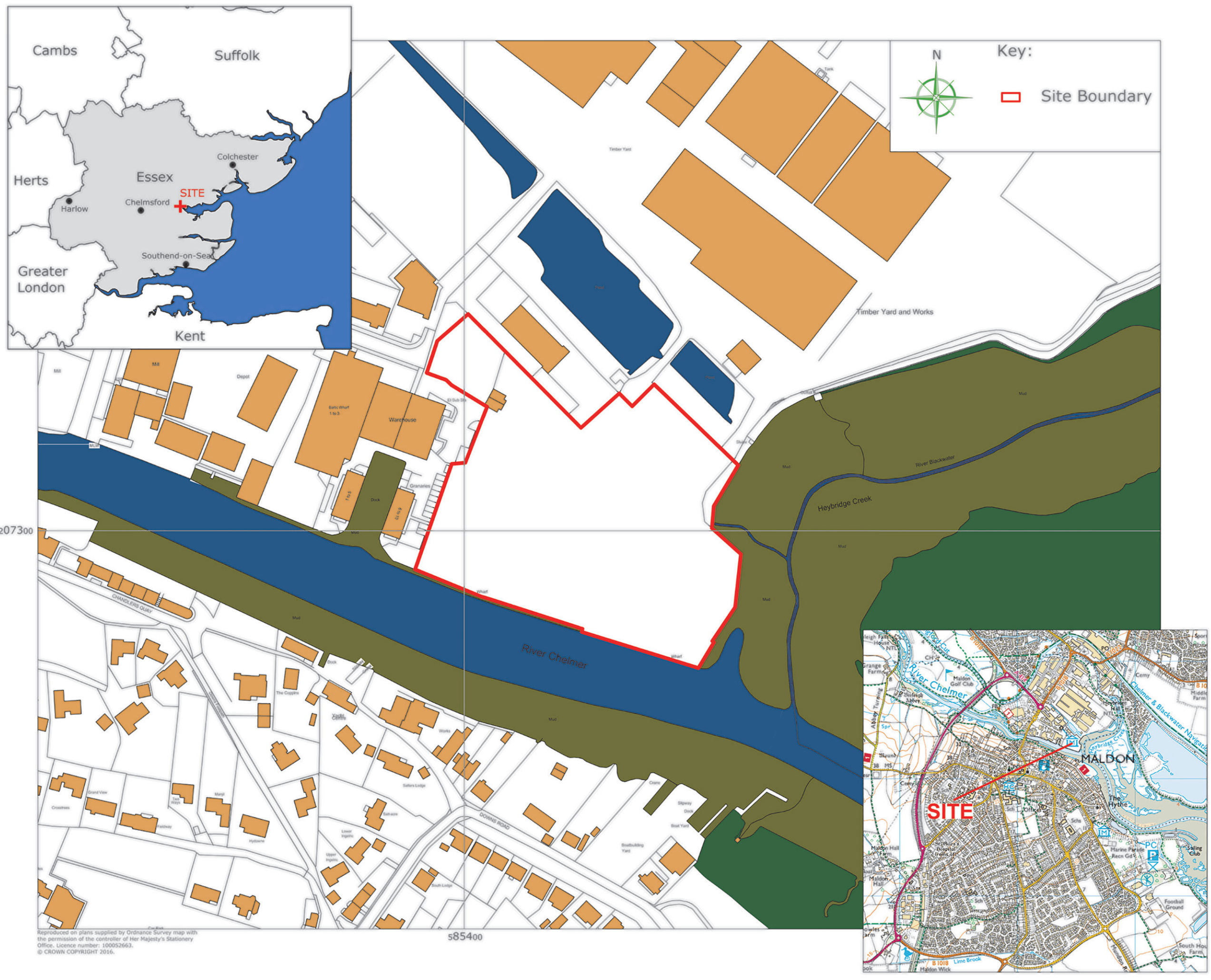


Figure 9.1: Location plan of the development site immediately adjacent to the river Chelmer and within the wider Essex landscape

evaluation sought to determine the location, character and level of preservation of surviving cultural remains, in particular, those associated with the now demolished Sadds Steam Saw Mill in the northern part of the site. Whilst the geoarchaeological investigations were restricted to the depth of impact of the proposed development, the scheme included the construction of basement parking and hence the proposed depth of investigation was significant.

9.3. Methodology

The deposit model was completed in two phases (Brook 2014). Phase 1 involved two cable percussion borehole transects across the site (Figure 9.2) aimed at assessing the thickness and character of the deposits. The transects (A and B) were aligned north to south and east to west. In total, eight boreholes were drilled along these lines, with a ninth borehole situated on the higher ground to the northern edge of the site, located in order to test deposit depth away from the alluvial zone. Each borehole location was surveyed using a differential global positioning system, (DGPS). The cores from the boreholes were extracted on-site using U100 tubes in Perspex sheaths (100mm in diameter and 450mm in length), allowing undisturbed samples to be retained, described and sub-sampled in the laboratory for further palaeoenvironmental analysis and radiocarbon dating. All natural and cultural strata that were observed in the cores were described on *pro forma* recording sheets.

Phase 2 involved the creation of a deposit stratigraphic model based on the borehole logs and, where appropriate, informed by the palaeoenvironmental analyses and radiocarbon dating of selected core sub-samples. Particular attention was paid to the presence or absence of pollen and mollusca within the alluvial layers, adding a layer of palaeoenvironmental data to augment the sedimentary descriptions.

Subsequent to the borehole survey, trial trenches were cut by a mechanical excavator under the supervision of a qualified professional archaeologist. The modern overburden was removed to the first archaeological horizon (Figure 9.3), and thereafter, all excavation work was undertaken by hand. Archaeological remains were preserved by record using *pro forma* sheets, plans, section

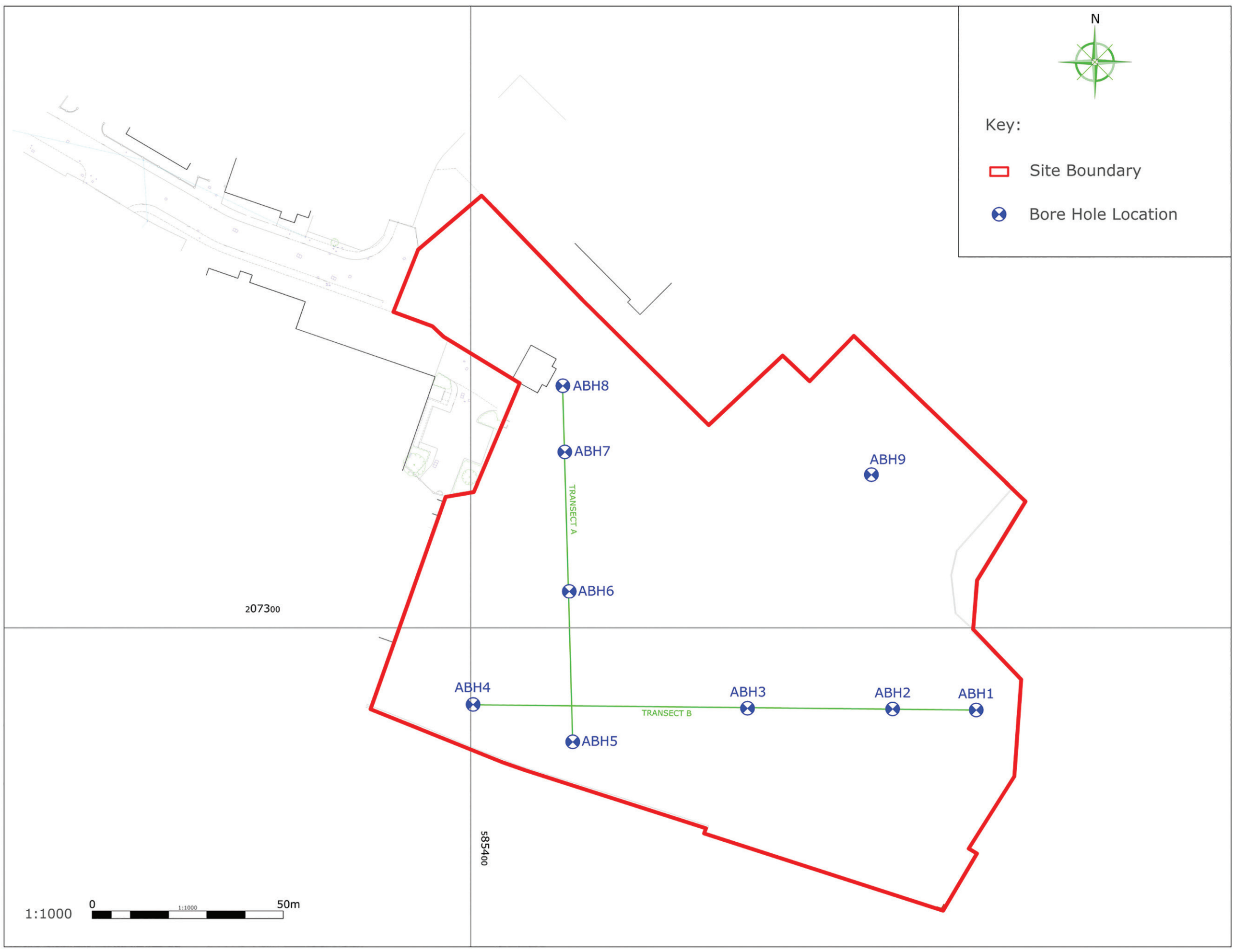


Figure 9.2: Position of boreholes within the immediate site area. Boreholes were drilled using a cable percussion rig with samples taken in U100 tubes for further analysis

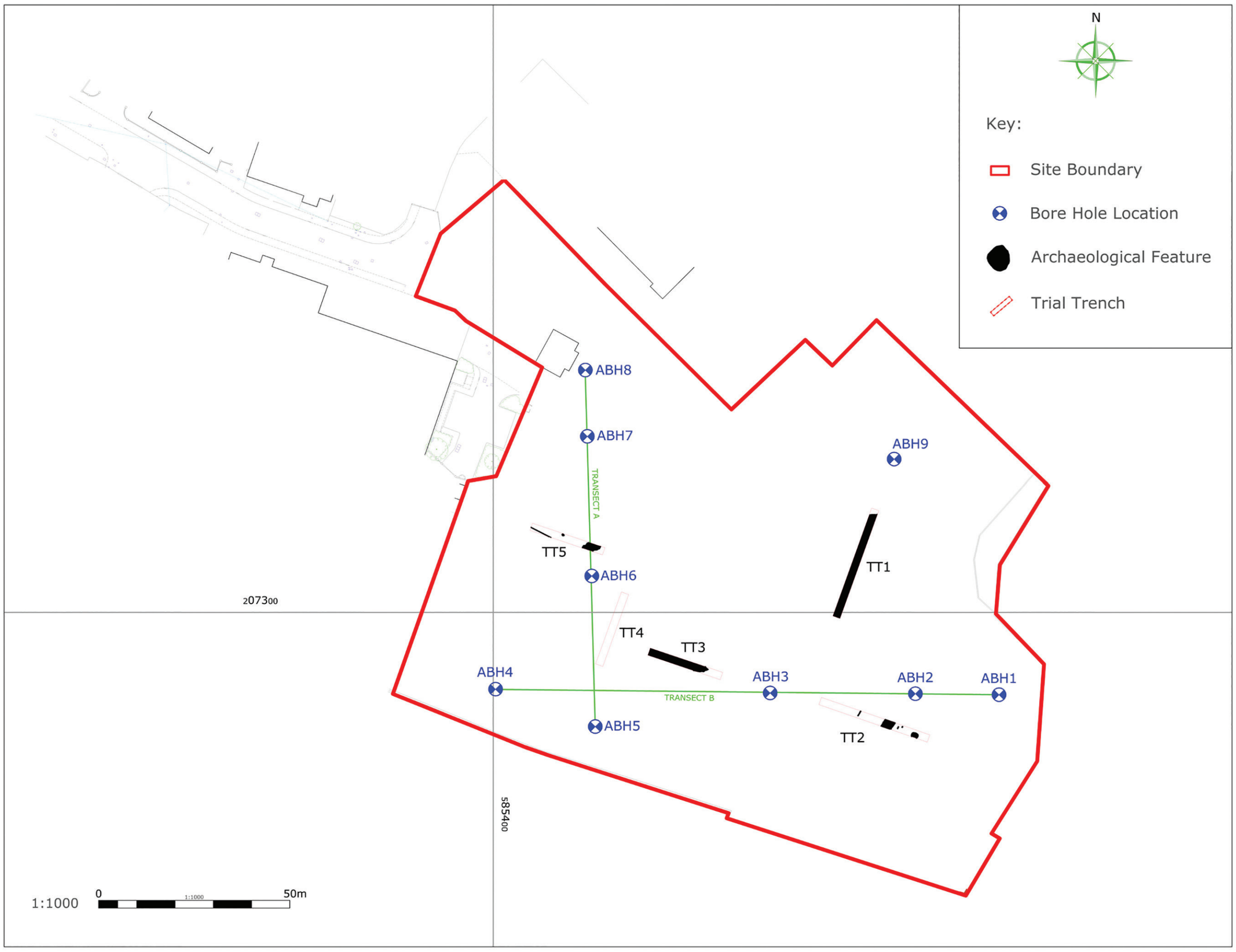


Figure 9.3: Trail trench positions in relation to borehole transects. The location of archaeological features recorded in trial trenches is also shown

drawings and photography. All layers were given unique context numbers, assigned during recording on-site. The sediments observed within these trial trenches were correlated with the stratigraphy recorded in the borehole survey to provide an overall stratigraphic model (Brook 2014).

9.4. Interpretation

The stratigraphic sequence recorded across the site was largely uniform despite the significant degree of ground disturbance caused by multiple phases of demolition and subsequent redistribution of material over the site to level the ground. From the information obtained through the borehole transects, a deposit model was constructed (Figure 9.4).

The top of the stratigraphic sequence consisted of a modern, made ground layer, which varied in thickness to a maximum depth of 1.30m. A spatially restricted demolition layer, associated with the former buildings of the John Sadd Timber Yard, was recorded below the made ground layer. This layer comprised an ash deposit that could relate to *in situ* burning associated with demolition of the buildings at the end of the 20th century or with a major fire that is recorded in 1907.

Four key stratigraphic units were recorded in the borehole survey beneath the modern made ground deposits. These units comprised an upper sandy gravel interpreted as a reclamation layer, above estuarine clays and gravels, river gravels and silts, and London Clay bedrock; they are each described in turn below.

Reclamation layer (1002)

This layer comprised light yellow-orange, loose sandy gravel with frequent large, rounded flint clasts. This unit is interpreted as the result of anthropogenic deposition of sediment across the eastern part of the site; it was spread across the area to raise, consolidate and reclaim an area of saltmarsh and to allow expansion of the Sadds Timber Yard. This episode of reclamation gives the site its current outline and topographic form. The line of the former sea defences was revealed during ground investigations in Trench 2 and is shown on the 1873 Ordnance Survey map (Figures 9.5 and 9.6), marking the eastern limit of this

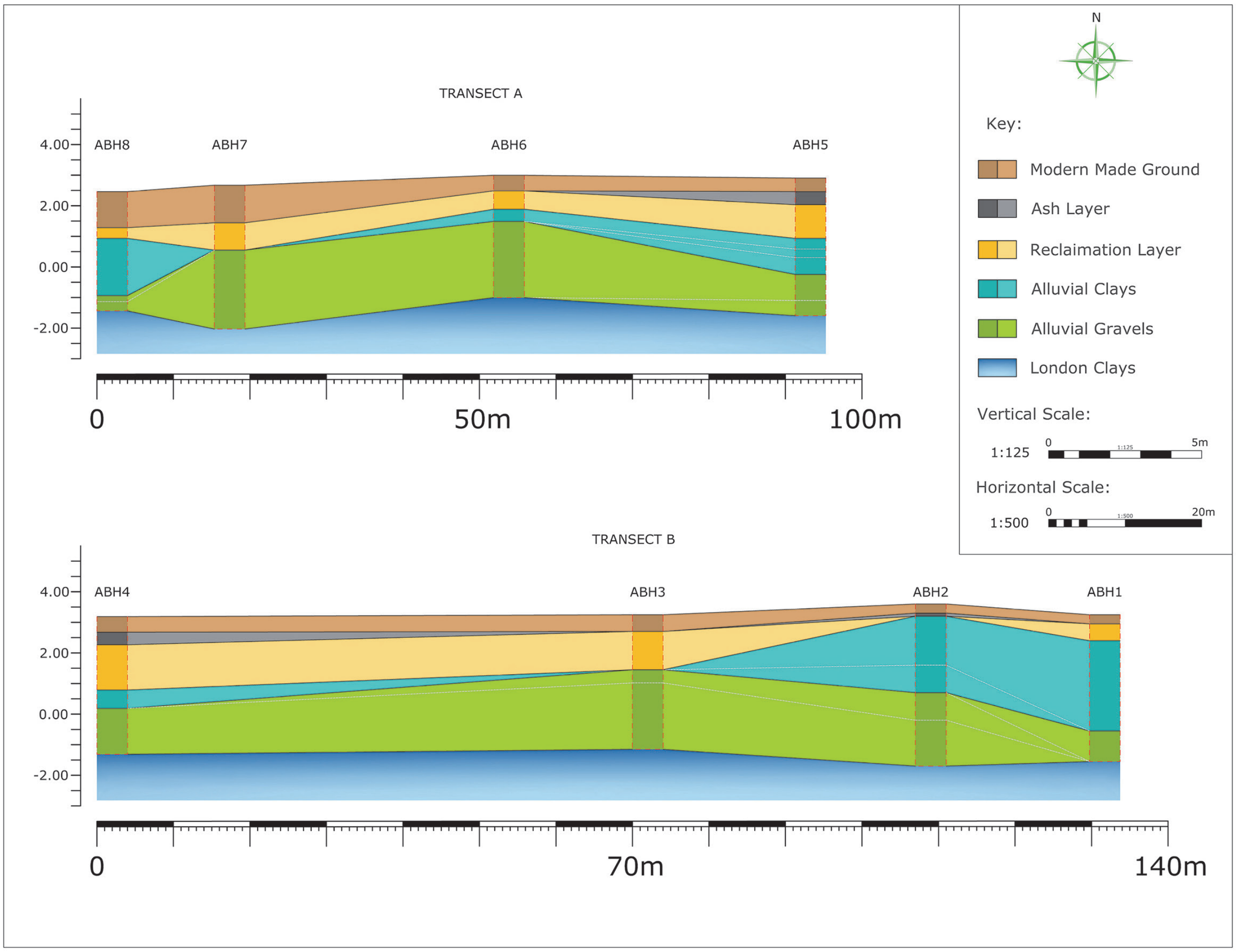


Figure 9.4: Archaeological deposit models constructed along Transects A and B

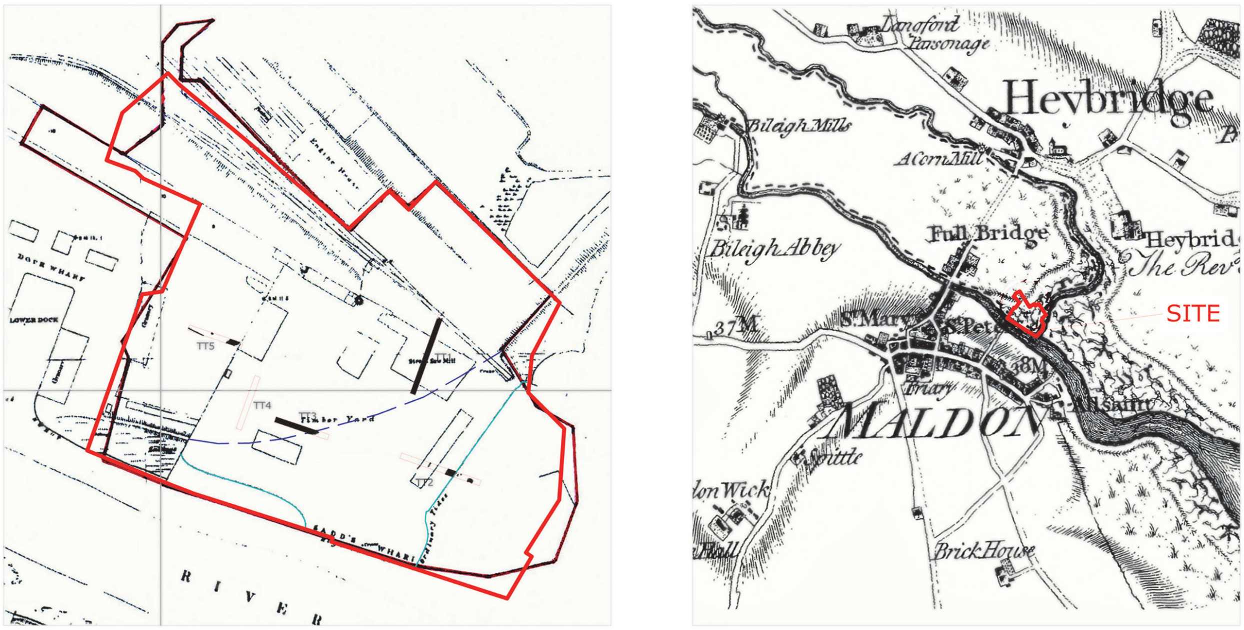
stage of reclamation. Trench 2 was located in the former intertidal zone, and this area of the site presumably required more material for consolidation than the remainder of it. This observation is demonstrable in Trench 5 where this reclamation layer is only recorded at the eastern end of the trench and is only 0.42m thick; the layer is absent at the western end of the trench reflecting an area of dryer, higher ground, which was already in use at the time of the consolidation of the eastern portion of the site.

Estuarine clay layer (1003)
This layer comprised dark blue-black, compact silty clay with infrequent small, sub-rounded flint clasts. This unit is interpreted as estuarine sediments deposited in a saltmarsh environment prior to the consolidation and reclamation of the site represented by Layer 1002. A wooden structure was located in Trench 3 on top of the silty clay (Figure 9.6) and is interpreted as a probable timber causeway constructed to facilitate access across the wetland.

Estuarine clay and gravel layer (1004)
This layer was recorded below the blue-black silty clay and comprised a light blue-brown, firm, mottled silty clay with small sub-angular gravel clasts. The layer is interpreted as an estuarine deposit aggraded in the intertidal zone close to the confluence of the rivers Chelmer and Blackwater.

Basal river gravels and silts layers (1006, 1007)
Underlying the estuarine deposits, a sequence of mid yellow-brown, loose gravel with frequent sub-rounded flint clasts was recorded. These sediments are interpreted as representing the sands and gravels of late Pleistocene and early Holocene date that infill the lower parts of the palaeovalleys of the Chelmer and Blackwater prior to sea level rise at the end of the last glacial stage. As well as being buried beneath later, finer-grained alluvial deposits, these sediments also crop out as higher gravel islands in the valley floors.

London Clay layer (bedrock, 1008)
Boreholes encountered the London Clay (bedrock) at an average depth of 5.3m across the site.



Ordnance Survey 6 Inch Series, 1873. Andre & Chapmans Map of Essex, 1777.

Figure 9.5: Map regression illustrating the physiography of the site at key points in time. The position of the archaeological trenches is shown on the map of AD 1873

DP8: Sea Defences - View West. DP10: Timber Causeway - View West.

Figure 9.6: The timber causeway and sea defences exposed during trial trenching at the site

The stratigraphy observed across the site demonstrates topographic variability within the natural saltmarsh surface; this would have required, therefore, varying levels of remediation and reclamation in order to create drier areas for human activity. In addition to the dumping of sediments to raise ground levels, recorded archaeological structures, including sea defences and a causeway, reflect other ways in which local communities overcame the physical environment to utilise the area. The discovery of the causeway across the estuarine clay confirms the presence of buried archaeological remains and reinforces the approach taken to 3-dimensional modelling of the site. The estuarine clays were thickest in the east, representing the area that had most recently formed part of the intertidal zone. Unfortunately, no peat deposits, which would have provided material for dating were recorded, however associated pottery recovered from the causeway dates from the late 17th century. The assessment for pollen of clay sub-samples from borehole ABH 5 revealed an absence of pollen (from the Estuarine Clay layer), strongly suggesting protracted sub-aerial exposure – thus supporting the documentary evidence for a saltmarsh environment in the Post-Medieval period. The absence of estuarine clays in borehole ABH 6 and the elevated position of the first layer of gravel deposits (1006 and 1007) are of particular interest, suggesting that the intertidal zone incorporated a series of gravel islands raised above lower areas infilled with finer-grained alluvial sediments.

9.5. Further field investigation

The archaeological evaluation which followed borehole modelling revealed four phases of site development. The earliest sedimentation phase was represented by gravel deposition by the local rivers in channels at the interface of the terrestrial and intertidal zones (Layers 1006, 1007). The local environment comprised marshland and bog separating higher gravel islands. No archaeological phases correlating with discrete anthropogenic sediments believed to be earlier than the Post-Medieval period were recorded. Cartographic evidence illustrates that the site was located in marshland until at least the middle of the 19th century. Andre and Chapman's AD 1777 Map of Essex (Figure 9.5), for example, shows little or no development of the area, marked as marshland and records the causeway crossing the site. This is in contrast to the AD 1873 6 Inch Series Ordnance Survey map (Figure 9.5), which shows significant development of the site that is clearly marked 'Timber Yard'.

The evaluation revealed the presence of a probable timber causeway (Figure 9.6). Nationally, there is very little evidence of Post-Medieval timber causeways and thus information on their construction, including preferred materials and techniques, is limited. Timbers sent for further analysis show that the causeway was probably built from off-cuts of timber processing (Bale and Nayling 2014). This can be seen in the presence of bark edges on the timber that would have been of little use commercially but would have been suitable for use as a stabilising surface on wet ground. The cartographic evidence indicates a timber industry in the vicinity of this site from at least AD 1777, when the first evidence of the causeway appears in the historic record. Unfortunately the analysis of the timbers by Dr Roderick Bale has not helped to provide an absolute date, and none of the timbers that proved to be oak were considered suitable for dendrochronological dating.

It should be noted that the probable timber causeway was not present in Trench 4, which ran perpendicular to Trench 3 and only 10m west of the trench. The reclamation layer (1002) is particularly deep in Trench 4, and it is possible that either the causeway did not extend this far or (more likely) that some timbers were removed or destroyed when the reconsolidation of the site commenced. Another possibility is that the causeway was discontinuous, comprising several discrete lengths connecting drier areas of the marsh. This was demonstrated in boreholes ABH 3 and ABH 6, where no estuarine clays were encountered. In both cases, however, the basal river gravels (1006) were recorded at a shallower depth, again suggesting small, elevated gravel islands within the wider floodplain.

9.6. Conclusions

The deposit model was created to provide an assessment of the geoarchaeological potential of the site and to correlate visible topographic features with the subsurface topography and geology. In the absence of a deposit model, a full interpretation of the natural evolution of the site and its development in relation to key archaeological features (the probable timber causeway and tidal defence structures) and the former intertidal environment would have not been possible.

It is interesting to note that the timber causeway runs on an alignment towards the location of borehole ABH 6, suggesting that the causeway may have comprised several lengths linking higher gravel islands and overlying estuarine clays. The causeway created a barrier in some areas, thereby enhancing sedimentation and making the marshland higher, wetter and difficult to navigate.

Further excavations are planned at the site and will provide an opportunity for the full extent of the timber causeway to be mapped and defined within the sites boundary. The deposit model constructed during this initial phase of investigation may be expected at that stage to contribute significantly to the interpretation of the archaeological record.

Acknowledgements

Britannia Archaeology Ltd would like to thank Mr Jeffrey Ciffer (The Baltic Consortium) for commissioning and funding the project, Maria Medlycott at Essex County

Council for all her advice and assistance throughout the project, Dr Steve Boreham (Cambridge University Department of Geography) for his advice and analysis of the soil samples and to Dr Roderick Bale (University of Wales Lampeter Archaeological Services) for his help and advice regarding the recording and analysis of the timbers.

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Constructing a deposit model: Sadd's Wharf

Assess pre-existing data

- British Geological Survey mapping
- Aerial photographs
- No LIDAR information available at time of project
- Single piece of pre-existing geotechnical information available from a borehole
- Physical site visit

Develop rationale for model construction and key aims and objectives

- Assess geoarchaeological potential
- Assess visible topographic features
- Cores from boreholes were retained, processed and described for possible future analysis
- Map and reconstruct the interpreted extent of reclamation

Can the deposit model be constructed using pre-existing data?

- No

Commission further groundworks, including:

- Trial trench evaluation

Construct deposit model comprising of one or more of the following:

- Contour maps of unit thickness
- Cross-sections and fence diagrams

Ground truth the deposit model through fieldwork and relate back to rationale of commission, aims and objectives:

- Trial trenches used to test upper deposits and define wider extent of reclamation
- Further work required to map fully the archaeological assets found in the trial trenching; additional examination of the deposit model may be necessary at this stage

Revise final product:

- Deposit model updated with results from trial trenching
- Mapping relationship of archaeological deposits to geological sediments

Archive and reuse:

- Data and reports archived with Essex County Council and Essex HER

SECTION 5

Modelling beyond a single site

10. Deposit modelling in the Lower Thames Valley (East London): correlating the sedimentary sequence with archaeological and palaeoenvironmental evidence of prehistoric human activity

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Abstract

Several years of geoarchaeological investigation in the London Boroughs of Newham and Greenwich, arising from archaeological mitigation of construction impacts, have resulted in a database of over 2000 stratigraphic records on the floodplain of the lower Thames Valley. This data has been used to develop a high-resolution spatial and temporal model of the floodplain landscape during the Late Devensian/Holocene, providing an opportunity to assess the potential of such a model as a predictive tool for identifying evidence of human activity and for locating thick sequences of palaeoenvironmental potential. The models have revealed a number of topographic features of interest in both Boroughs, including gravel highs and possible late Devensian/early Holocene channels. The models demonstrate that in general, greater thicknesses of alluvium are recorded in areas of lower gravel topography as might be expected, but that peat thickness shows a less predictable relationship with the underlying gravel topography. The distribution of the known prehistoric archaeology suggests that such sites have thus far only been recorded in areas of gravel 'highs' (generally above -1m OD), and that many of the sites are recorded where the peat is either relatively thin (<1m) or absent. The model highlights the importance of larger-scale deposit models in areas subject to intensive redevelopment and demonstrates that such models can be a useful tool in identifying areas of palaeoenvironmental and archaeological potential.

10.1. Introduction

The deposit model presented here forms the basis of a forthcoming publication, created in order to examine the potential of such a model to establish the archaeological and palaeoenvironmental significance of the floodplain in two areas of east London: the Borough of Newham, north of the River Thames, and the Royal Borough of Greenwich, south of the river. Such an exercise was facilitated by several years of geoarchaeological investigations in these Boroughs, undertaken by QUEST in collaboration with a number of archaeological units and heritage consultants; these resulted in a large body of sedimentary, palaeoenvironmental and archaeological evidence that also draws on existing geotechnical and archaeological databases (for example, the British Geological Survey [BGS] and Greater London Historic Environment Record [GLHER] archives) and site-specific geotechnical, geoarchaeological and archaeological investigations. The deposit model was initially presented as a poster at the Conference on the *Environmental Archaeology of European Cities* (27th-29th May 2015) in Brussels. The sedimentary data was therefore compiled, interrogated and interpreted over several years by QUEST geoarchaeologists, with a more thorough interrogation of the data undertaken more recently by the authors using deposit modelling software (RockWorks 16). Since the deposit modelling exercise was not directly funded by commercial work, funding was sought from a variety of sources, including an initial phase of data compilation conducted as part of the Undergraduate Research Opportunities Placement (UROP) scheme (funded by the

Comparative data table of this deposit model	
Deposit model location	London Borough of Newham and the Royal Borough of Greenwich, east London(NGR centred on: 540220 180130)
Depositional environment	Floodplain in the lower Thames Valley
Size of deposit model	Approximately 1,100Ha
Data collection strategies	Combination of British Geological Survey archive boreholes, site-specific geotechnical (borehole and test pit) data, and site-specific geoarchaeological boreholes
Position in the archaeological process	Prepared for publication, collating various site-specific geoarchaeological site investigations
Reason for deposit model construction	To produce a model of the sub-surface stratigraphy across the two Boroughs, including the surface of the late Devensian gravel, and the surface and thickness of the subsequent Holocene alluvial deposits
Archaeological question	To predict where evidence of human activity might be preserved, to place that evidence in its environmental context, and to establish how human activity influences, and is influenced by, environmental change
Software and modelling process	Data sorted in Excel and then imported to RockWorks 16. Models generated using an Inverse Distance Weighting algorithm. Output grid files modelled as raster files in ArcGIS
Outputs from the deposit model	A series of topographic surface plots, thickness models and selected representative cross-sections; assessment of archaeological and palaeoenvironmental potential

University of Reading). The time spent on the deposit modelling was ultimately funded by the University of Reading, who recognise the publication output of QUEST as a contribution to academic research.

10.2. Objectives

The overall objective of the study was to construct a high-resolution deposit model of the floodplain landscape, and to examine the interactions between topography, hydrology, vegetation and human activity in this part of east London. Ultimately, it was hoped that the model would help to: (1) predict where evidence of human activity might be preserved, and to place that evidence in its environmental context; (2) establish areas of greater palaeoenvironmental potential; and (3) establish how human activity influences, and was influenced by, environmental change. The sediment sequence beneath the floodplain in this area of the lower Thames Valley is well-documented, consisting of Pleistocene river gravel (the Shepperton Gravel) overlain by finer-grained Holocene alluvial deposits, often including peat, and masked by Made Ground (derived from waste material, demolition debris and redeposited alluvium).

The boundary surfaces between these sediment types are of interest since they represent evidence of local and regional environmental change. The most significant surface is that of the underlying Pleistocene gravel which, influenced by relative sea-level change and changing river behaviour, has largely determined the pattern of Holocene sedimentation in this area of the Lower Thames Valley.

Landforms, such as palaeochannels and gravel islands (eyots), have been identified in the surface of the Pleistocene gravels and their topographic form (altitudinal expression) have implications for soil formation, the location of archaeology and the potential for peat formation. The construction of a deposit model should enable the researcher to identify areas with higher archaeological potential. For example, areas of raised gravel topography may have increased archaeological significance, as demonstrated by analogous areas such as the Horselydown Eyot (Leary *et al* 2011), the Bermondsey Eyot and beneath the Royal Docks Community School (Holder 1998), all of which have all yielded evidence of utilisation and/or occupation by prehistoric people. In addition, peat forming in palaeochannels and other depressions on the margins of gravel highs and other dryland areas probably has a higher potential of containing prehistoric structures, as is demonstrated by a number of Neolithic and Bronze Age trackways, platforms and causeways at sites such as Golfers Driving Range, Beckton (Carew *et al* 2009). Finally, modelling allows the identification of areas where thick sequences of peat and alluvium are likely to be located; these have the potential to preserve high-

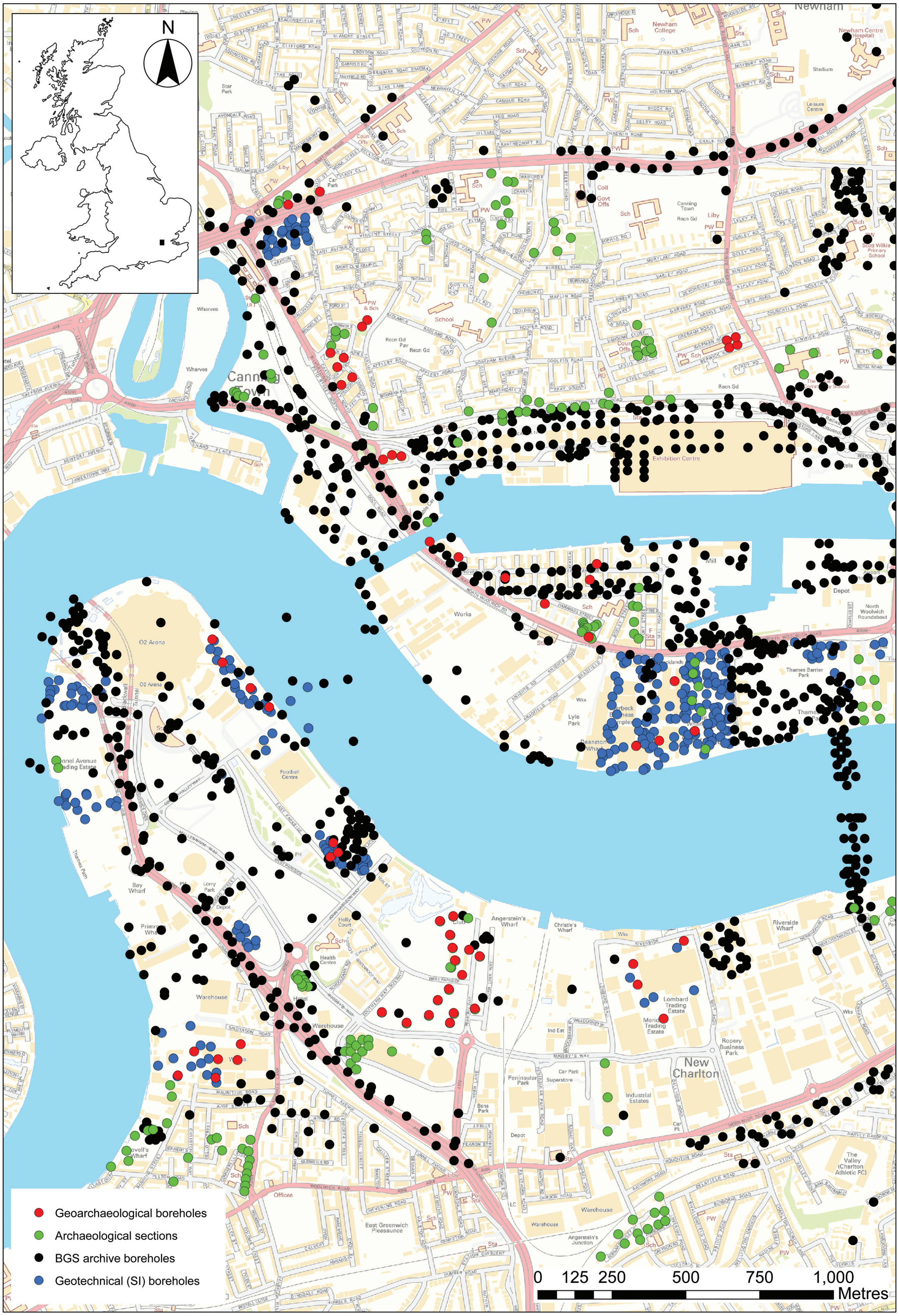

Figure 10.1: Records used in the deposit model for the London Boroughs of Newham and Greenwich: geoarchaeological boreholes, archaeological sections, BGS archive boreholes and site-specific geotechnical interventions. Contains Ordnance Survey data © Crown copyright and database right [2016]

Figure 10.2: Location of selected geoarchaeological and archaeological sites in the area of the deposit model. Contains Ordnance Survey data © Crown copyright and database right [2016]

resolution proxy palaeoenvironmental records of climate change, vegetation history, past hydrological regimes and human activity.

10.3. Methodology

The deposit model incorporated over 2000 records from a number of site-specific geoarchaeological, archaeological and geotechnical investigations, with the addition of borehole scans from the British Geological Survey (BGS) geoindex (http://mapapps2.bgs.ac.uk/geoindex/home.html) (see Figures 10.1 and 10.2). The data were compiled, interrogated and entered into the deposit modelling software during previous site investigations in the two Boroughs over a period of several years. It became apparent during this exercise that many of the geotechnical records from both site-specific investigations and the BGS geoindex were lacking sufficiently accurate spatial information (location and elevation), with geoarchaeological and archaeological records tending to be more reliable. With this in mind, only those records that included these data were included in the models. In addition, it was important to recognise at this stage that multiple sets of boreholes were represented; these were drilled at different times and recorded using different descriptive terms, and were subject to differing technical constraints in terms of recorded detail (including the exact levels of stratigraphic boundaries). An additional complication was presented by those records from the area of Royal Victoria Dock (Borough of Newham) where substantial excavation and subsequent infilling of the western inlet from the Thames created challenges for stratigraphic interpretation.

The initial phase of work involved the inspection of geotechnical logs from site-specific investigations and the BGS geoindex; those that were considered reliable were divided into their relevant sedimentary units, with the depth of the upper surface of each unit recorded in an Excel spreadsheet. The same data from geoarchaeological boreholes, including those drilled during site-specific investigations by QUEST and those recorded in unpublished (for example, http://archaeologydataservice.ac.uk/archives/view/greylit/query.cfm) or published accounts relating to other sites, were also inputted to Excel. Finally, relevant stratigraphic data from archaeological sections recorded in published and unpublished sources was also compiled. The spatial and stratigraphic data were then imported to RockWorks 16, using the 'Import from spreadsheet' function.

Topographic surface plots and thickness models were generated for each of the main stratigraphic units, using an Inverse Distance Weighting algorithm to optimise the smoothness of the interpolated outputs. Despite the number of available records for the two Boroughs, the boreholes are not uniformly distributed and a number of notable 'gaps' in the model may be observed. The reliability of the models is therefore variable. As a consequence of this the modelling procedure was manually adjusted so that only those areas for which sufficient stratigraphic data are present are modelled; in order to achieve this, a 'maximum distance cut-off filter' equivalent to a 100m radius around each record was applied to all deposit models.

The output from these models (in the form of RockWorks 16 grid files) was exported to ASCII format and then converted to Raster files within ArcMap. The Raster files were subsequently overlain on Ordnance Survey Street View mapping (open-source data) for the creation of the final models. Stratigraphic transects were generated using RockWorks 16 and were edited in Adobe Illustrator. Prehistoric archaeological data was compiled from the Greater London Historic Environment Record (GLHER). Figures 10.3, 10.4 and 10.5 illustrate the modelling of key units and surfaces, whilst Figures 10.7, 10.8 and 10.9 illustrate selected stratigraphic cross-sections (see Figure 10.6 for their locations).

10.4. Interpretation

10.4.1. Floodplain landscape evolution

Overlying the London Clay bedrock, a total of five main stratigraphic units were identified in the modelled area. These are described below, commencing with the modern ground surface:

- *Made Ground*: widely present and derived from waste material, demolition debris and redeposited alluvium;
- *Upper alluvium*: widely present across both Boroughs, usually clay-rich and largely inorganic. The sediments of the Upper Alluvium are considered to be indicative of deposition within low energy fluvial and/or estuarine floodplain environments associated with rising sea level during the Middle and Late Holocene. The high mineral content of the sediments probably reflects increased sediment loads resulting from intensification of agricultural land use from the later prehistoric period onward;
- *Peat*: frequently recorded across the floodplain but of variable thickness and recorded at differing depths; the peat often separates the deposits of the Upper and Lower Alluvium, but occasionally rests directly on the Pleistocene Shepperton Gravel. The peat is indicative of a transition towards semi-terrestrial (marshy) conditions, supporting the growth of sedge fen/reed swamp and/or woodland communities across the floodplain areas of both Boroughs;
- *Lower alluvium*: locally present, typically sandy/silty and frequently containing wood or macroscopic plant remains. The sediments of the Lower Alluvium are considered to be indicative of deposition by actively meandering channels during the Early to Middle Holocene, by which time the main course

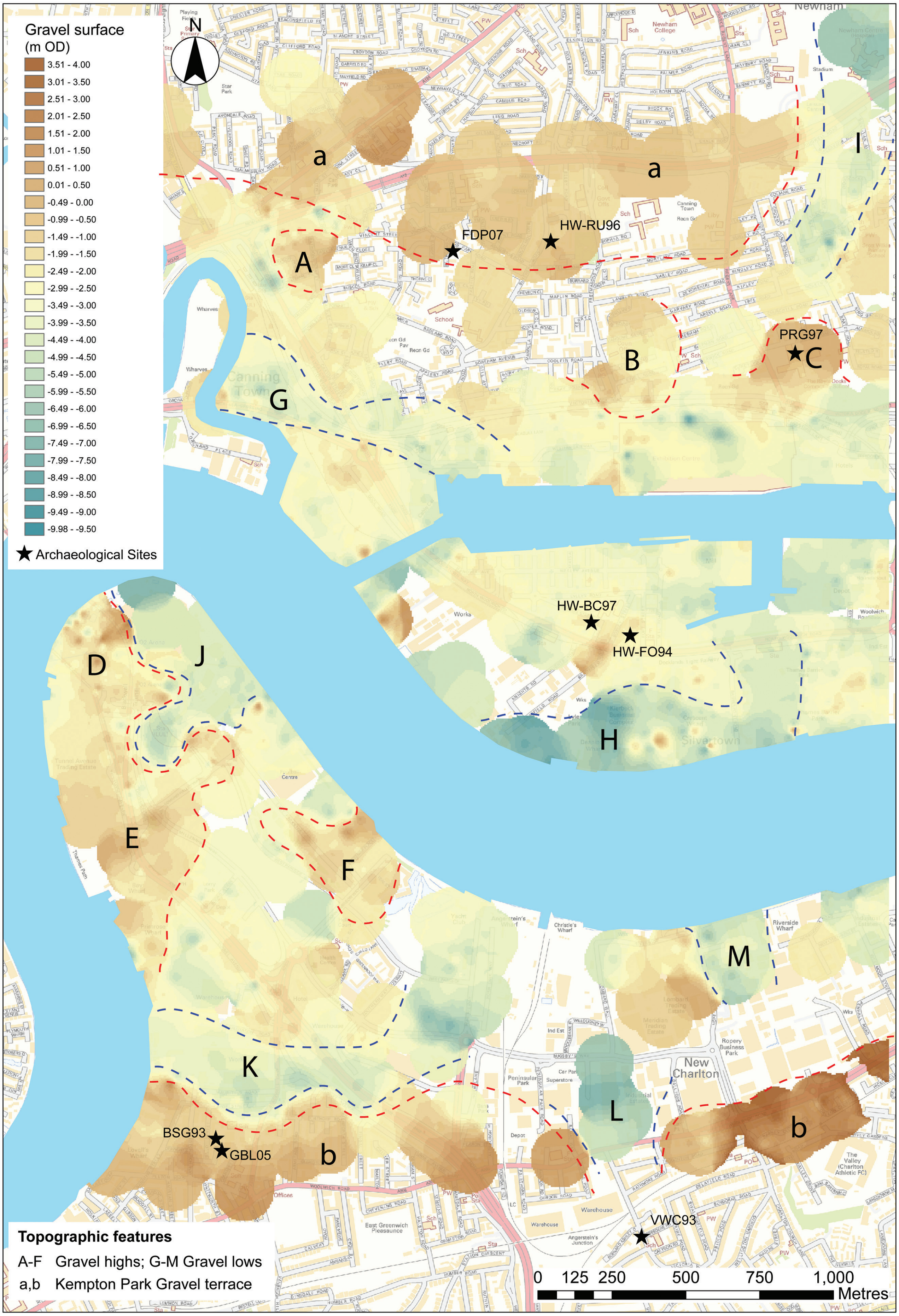

Figure 10.3: Modelled surface of the Pleistocene Shepperton Gravel (modelled using an Inverse Distance Weighting algorithm, with a maximum distance cut-off filter of 100m), showing the location of prehistoric archaeological sites and features described in the text. Contains Ordnance Survey data © Crown copyright and database right [2016]

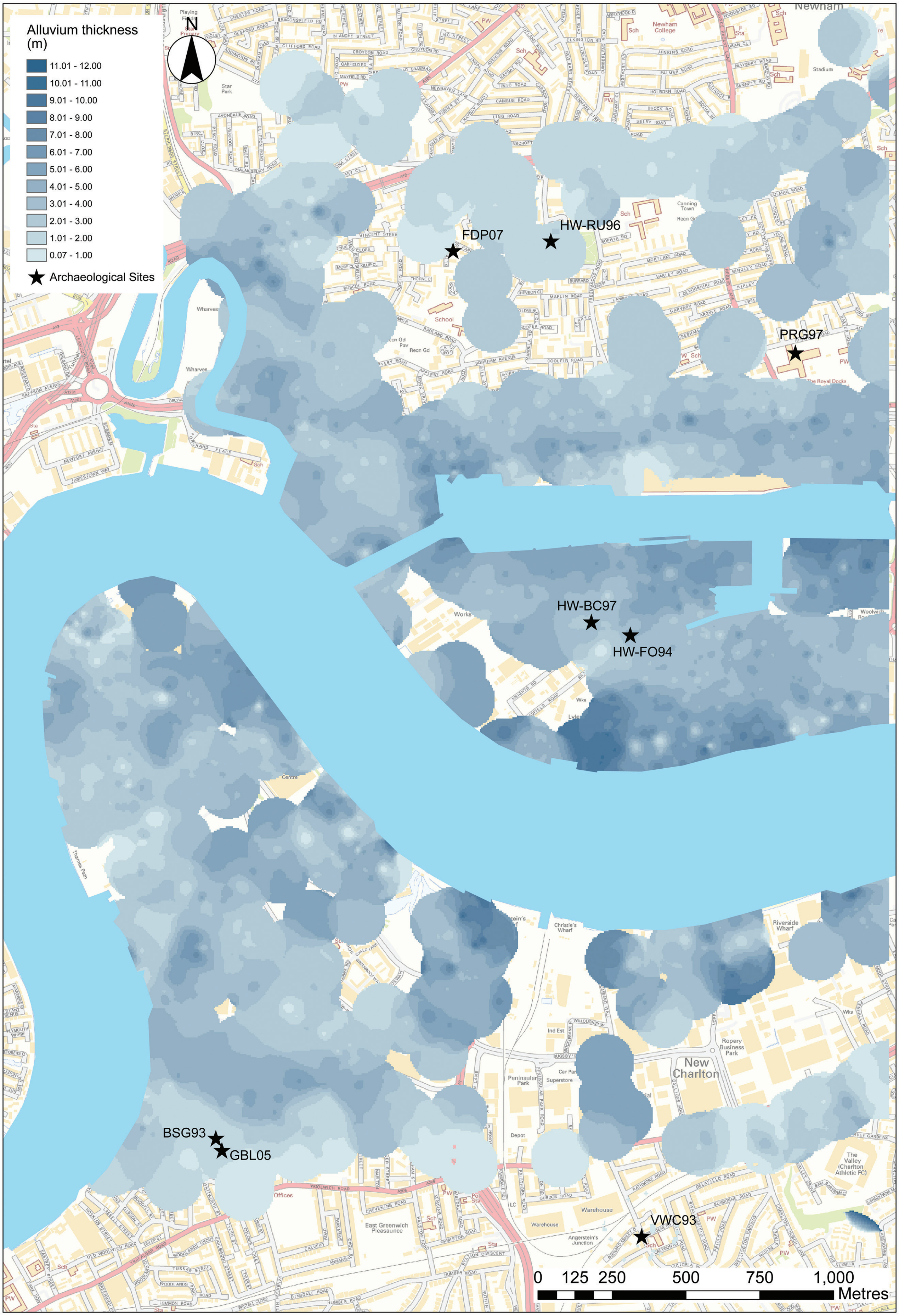

Figure 10.4: Modelled thickness of the Holocene alluvium (modelled using an Inverse Distance Weighting algorithm, with a maximum distance cut-off filter of 100m), showing the location of prehistoric archaeological sites (see text). Contains Ordnance Survey data © Crown copyright and database right [2016]

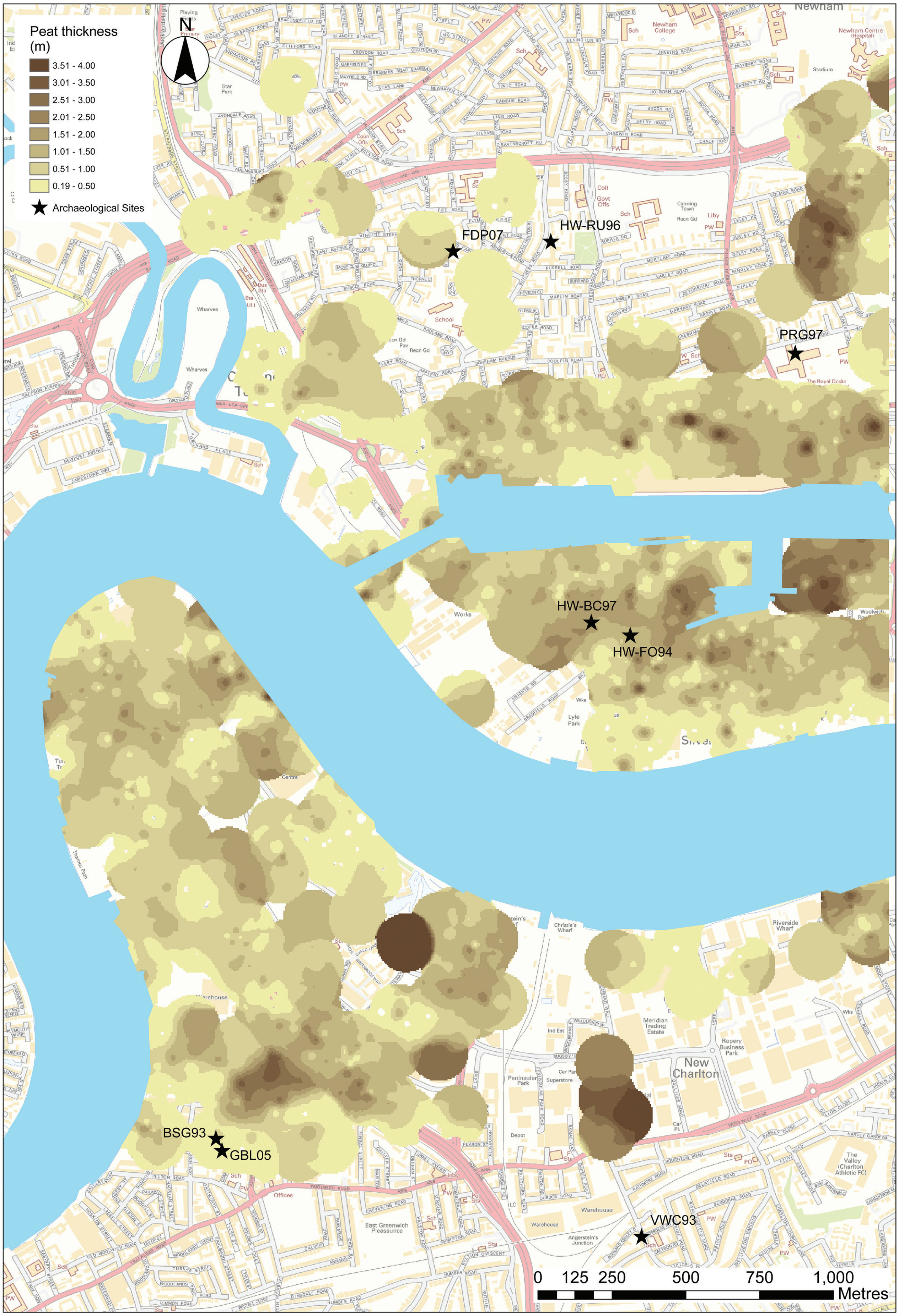

Figure 10.5: Modelled peat thickness (modelled using an Inverse Distance Weighting algorithm, with a maximum distance cut-off filter of 100m), showing the location of prehistoric archaeological sites (see text). Contains Ordnance Survey data © Crown copyright and database right [2016]

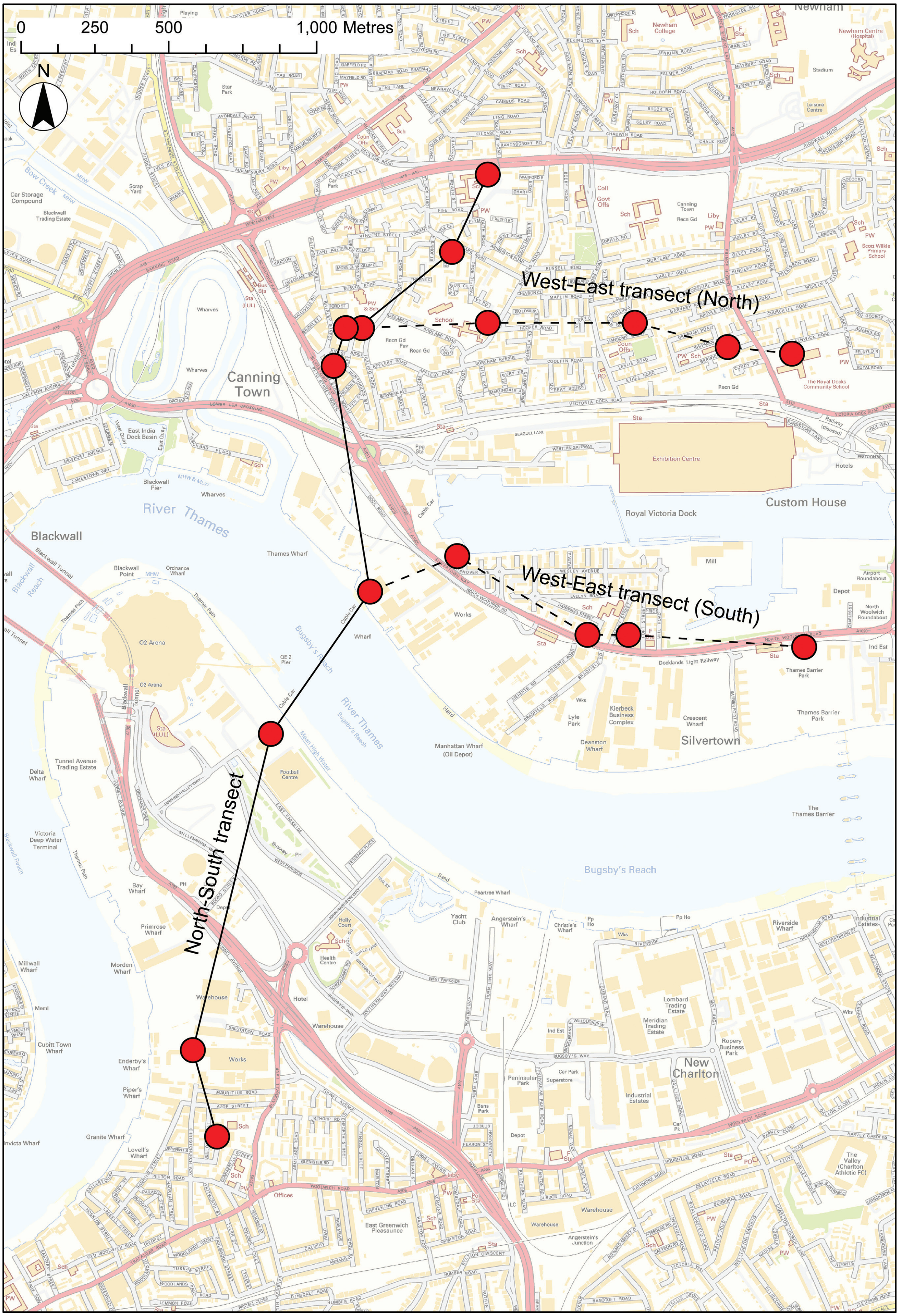

Figure 10.6: Map showing the location of the North-South and West-East transects. Contains Ordnance Survey data © Crown copyright and database right [2016]

of the Thames was probably established as a single channel close to its present alignment (although subsidiary, actively meandering channels appear to have survived elsewhere on the floodplain). During this period, the surface of the Shepperton Gravel was locally buried beneath sandy and silty channel and floodplain deposits. The distribution of the Lower Alluvium tends to confirm that this was a period during which the valley floor was occupied by a number of actively shifting channels, with a drainage planform pattern that was still determined to some extent by the underlying relief of the upper surface of the Shepperton Gravel;

- *Pleistocene sand and gravel*: sand and gravel is widely present across the modelled area, overlying the London Clay bedrock. Across much of the floodplain, and where it lies below *c* 0m OD, this unit is considered to represent the Shepperton Gravel, deposited during the Late-glacial period (15-10,000 years before present [BP]). Possible remnants of earlier Kempton Park Gravel (Middle Devensian; *c* 80-30,000 years BP) are recorded, in particular towards the southern and northern edges of the floodplain (see below); these perhaps form part of a 'low terrace', generally lying above *c* 0m OD. Both mappable lithostratigraphic units comprise sands and gravels deposited in a high-energy, braided river system; the latter, while it was active, would have been characterised by longitudinal gravel bars and by intervening low-water channels in which finer-grained sediments might have accumulated. Such a pattern of floodplain relief and this sedimentation regime would have been present on the valley floor at the beginning of the Holocene, although this was a time of transition to a lower-energy fluvial regime.

The position of the former Holocene floodplain of the Thames can be defined within the deposit models, with rising gravel surfaces (0-1m OD; see Figures 10.3, 10.5, 10.7, 10.8 and 10.9) and successively thinner alluvial sequences towards the northern and southern boundaries of the floodplain (where possible remnants of the Pleistocene Kempton Park Gravel terrace are recorded as features 'a' and 'b' on Figure 10.3). The model of the Shepperton Gravel has also revealed a number of topographic features of interest in both Boroughs (see Figure 10.3) including:

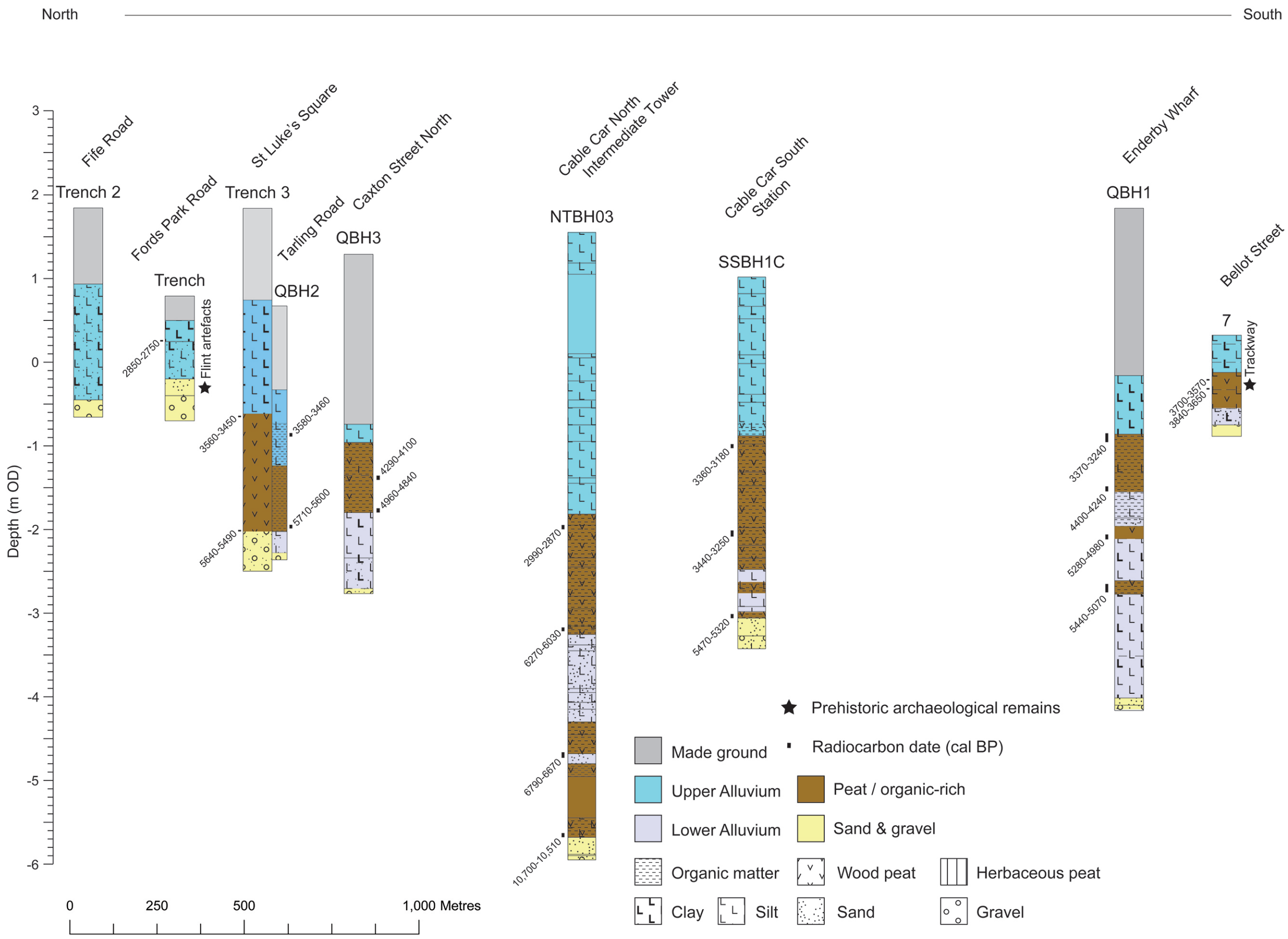

Figure 10.7: Selected lithostratigraphic sequences along a North-South transect across the modelled area (see text)

- Gravel highs, where gravel surfaces are recorded at between -2m and 0m OD (features A-F). These may represent either 'eyots', composed of Shepperton Gravel, or remnants of the higher Kempton Park Gravel terrace;

- Low gravel topography (-4m to -8m OD) indicative of former late Devensian/early Holocene palaeochannels (features G-L). Features G (Newham) and K (Greenwich) are of particular interest; the former represents a possible relict meander of the River Lea and the latter a large, perhaps late Devensian channel that may pre-date the modern course of the Thames. Features I and L meanwhile appear to dissect the Kempton Park Gravel terrace in the northern and southern areas of the floodplain respectively, forming deep, subsidiary or tributary channels of the River Thames and/or River Lea.

The deposit models for the subsequent Holocene alluvial deposits demonstrate that, as might be expected, greater thicknesses of alluvium (5m-8m) are generally recorded in areas of lower gravel topography (for example, infilling palaeochannels; Figure 10.4). However, the thickness of the peat (Figure 10.5) shows a less predictable relationship with the underlying gravel topography. Although some of the channel features identified above are infilled by 2-4m of peat (for example, features K, L and I), some

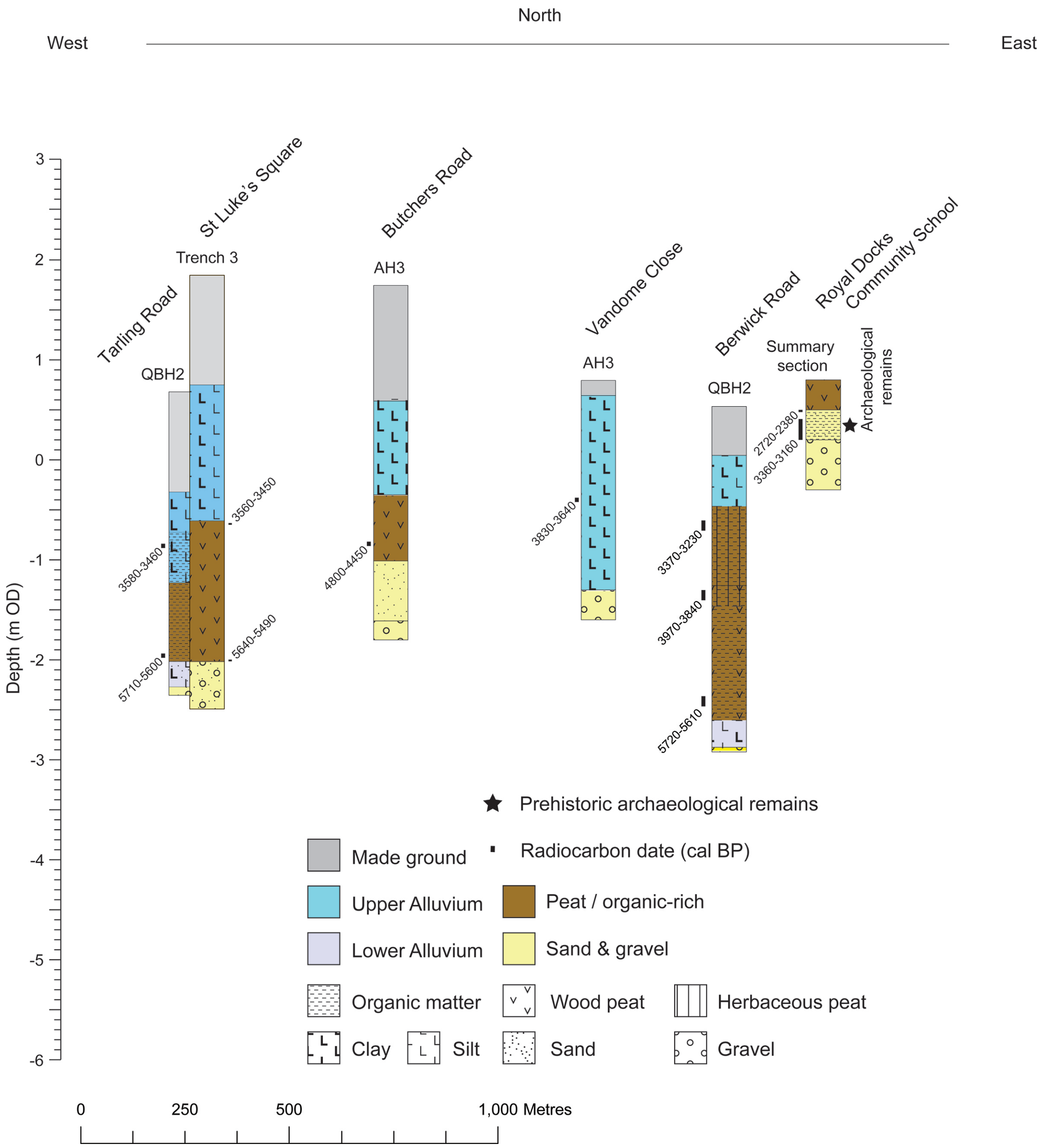

Figure 10.8: Selected lithostratigraphic sequences along a West-East transect (North) (see text)

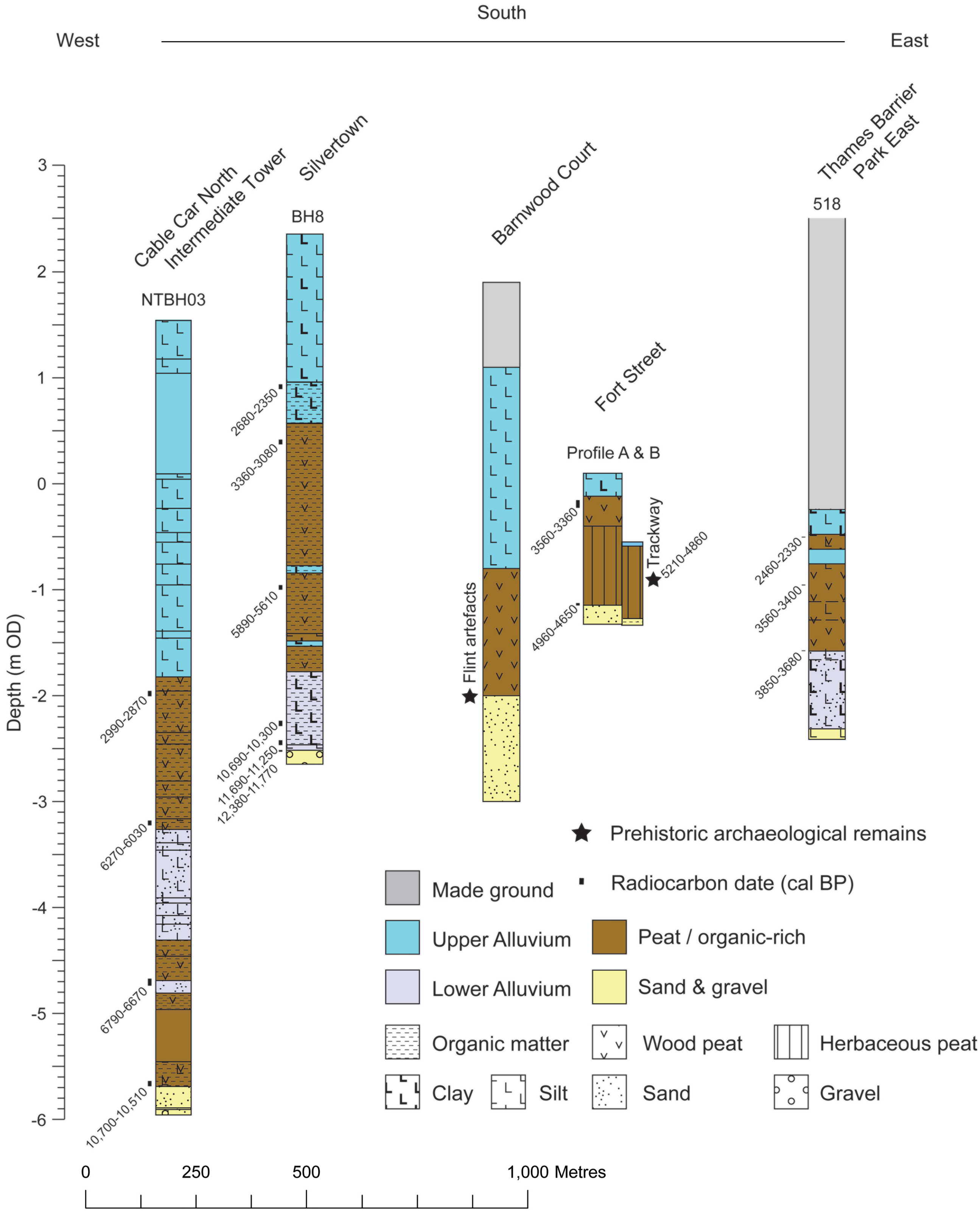

Figure 10.9: Selected lithostratigraphic sequences along a West-East transect (South) (see text)

Table 10.1: Prehistoric archaeological sites in the floodplain area of the London Borough's of Greenwich and Newham

Site name	**Site code**	**Description of prehistoric archaeological remains**	**Easting**	**Northing**	**Reference**
Royal Docks Community School, Newham	PRG97	>1300 fragments of Bronze Age and Neolithic flint tools and pottery recorded with a few Mesolithic flint tools, over a sand and gravel land surface.	541305	181105	Holder 1998
Victoria Way, Greenwich	VWC93	Various flints/burnt flints. Possibly not *in situ*	540785	178115	Bowsher 2003
Garage site, Bellot Street, Greenwich	GBL05	Bronze Age wooden structure (3840-3650 to 3700-3570 cal. BP) orientated north-west to south-east; recorded within the peat (-0.22m OD), above an elevated gravel surface (-0.70m OD)	539365	178405	Hawkins 2005
Barnwood Court, Newham	HW-BC97	6 fragments of burnt flint and 1 struck flint recovered from sand at *c* -1.81m OD; sealed by peat	540615	180195	Farid 1997
72-82 Bellot Street, Greenwich	BSG93	Bronze Age wooden structure (3550-3260 cal. BP) orientated north-south; recorded within the peat (-0.60m OD), above an elevated gravel surface (-0.58m to -0.79m OD)	539345	178447	Philp 1993
Butchers Road, Newham	HW-RU96	Small quantities of burnt and worked flint and a sherd of pottery (late Bronze Age?); recorded within peat	540478	181484	Wessex Archaeology 1996
Fort Street, Newham	HW-FO94	Short length of early Neolithic trackway of *Alnus* sp. (5210-4860 cal. BP); recorded within peat (-0.99m to -1.28m OD), above an elevated sand surface	540747	180151	Crockett *et al* 2002
20 Fords Park Road, Newham	FDP07	2367 struck flints, >2000 burnt flints and 44 pottery sherds recorded on a sandy eyot. The flint is largely later Mesolithic, with a few Neolithic/Bronze Age pieces	540148	181451	Nicholls *et al* 2013

areas of lower gravel topography coincide with relatively thin (<1m) horizons (G, H and M); in addition, thick peat horizons (2-3m) are recorded in the area of selected gravel highs (D, B). At least part of the variation in the thickness of the peat may be a result of erosion associated with later fluvial activity.

10.4.2. Archaeological and palaeoenvironmental potential

Both the palaeochannels and gravel highs identified above would have represented significant features in the prehistoric landscape in this part of the Lower Thames Valley floodplain. The distribution of known prehistoric archaeology in relation to the underlying gravel topography (Figures 10.3, 10.5, 10.7, 10.8 and 10.9) suggests that such archaeology has so far been recorded only in areas of gravel 'highs' (generally above -1m OD). Five of the eight known prehistoric sites (Table 10.1) are associated with high gravel features identified above, whilst the other two (HW-8C97 and HW-FO94) are recorded in an area of moderately high gravel (-1m to -2m OD). Regarding the relationship between prehistoric archaeological remains and peat deposits, many sites of this period are recorded where the peat is either relatively thin (<1m; GBL05, BSG93, HW-BC97, HW-FO94) or absent (for example, FDP07, HW-RU96, PRG97, VWC93). Perhaps notably, with the exception of those sites towards the northern edge of the floodplain, the remainder of the sites are located on gravel highs that lie close to or on the margins of deeper channel features (for example, features K and H). Such relationships thus indicate that in this area of the floodplain, around Newham and Greenwich, archaeological potential may be greater in areas of higher gravel topography, in particular those areas that lie close to or on the margins of palaeochannel features. However, it is important to note that more deeply stratified archaeology may be difficult to locate, and the rate of sea-level rise (and areas of inundation) may have been a significant factor in determining the location of earlier to later prehistoric activity.

The areas of thicker peat (3-4m in places) indicate locations which might provide long, continuous records of environmental change and human activity through the preservation of biological remains, which are of particular relevance in areas close to known prehistoric activity. A good example of this is channel feature K at Bellot Street (Greenwich), where up to 4m of peat is recorded within *c* 150m of a Bronze Age trackway (Philp 1993). The deposit models presented may therefore be used as a guide for future archaeological and palaeoenvironmental investigations in advance of development of these areas.

10.5. Further developments to the deposit model

Notable gaps have been identified in the deposit models, some of which are located in key areas, which might provide further information to aid our understanding of landscape evolution and archaeological potential in this part of the floodplain. These include the area to the south-east of Greenwich Peninsula, where the relationship between channel features K, L and M is poorly understood, the northern area of the floodplain around channel feature I and gravel highs A, B and C. Prior to future publication of the model, any newly available data from geotechnical, geoarchaeological or archaeological site investigations will be sought in order to refine it. At the time of writing, geoarchaeological investigations are underway in both Greenwich and Newham; data from these interventions will be incorporated into the existing models.

10.6. Conclusions

The London Boroughs of Greenwich and Newham are both the subject of significant programmes of redevelopment, which may be expected to provide valuable opportunities for further archaeological and geoarchaeological investigations. By highlighting archaeological and palaeoenvironmental potential in this highly dynamic floodplain landscape, the models presented here provide valuable tools for use by heritage managers, archaeological practitioners, consultants and their clients. This study emphasises the potential of larger-scale deposit models to enhance understanding and to inform evaluation and mitigation strategies in areas subject to intensive redevelopment, and demonstrates that such models can assist the development of more integrated approaches to archaeological and geoarchaeological investigation. None of these models, however, should be viewed as definitive, and it is intended that they be updated and revised over the coming years to integrate data from future archaeological, geoarchaeological and geotechnical site investigations.

Acknowledgements

We are grateful to the following organisations for commissioning Quest to carry out geoarchaeological investigations within the area detailed above: CgMs Consulting, RPS Planning & Environment, AOC Archaeology and Pre-Construct Archaeology.

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Constructing a geoarchaeological deposit model: Lower Thames Valley

Assess pre-existing data
- British Geological Survey boreholes
- Site specific geotechnical boreholes and test pit data
- Site specific purposive geoarchaeological boreholes

Develop rationale for model construction and key aims and objectives
- To model data from multiple different projects into one integrated deposit model
- To model the interface of the Late Devensian and Holocene
- Identify sediments of high palaeoenvironmental potential
- Predict areas of past human activity
- Establish how human activity influences, and was influenced by, the palaeoenvironment

Can the deposit model be constructed using pre-existing data?
Yes, the project utilised over 2000 pre-existing data points to construct the model in Rockworks 16

Commission further ground investigations, including:
No; although data from further ground investigations in specific development plots can be added to the model

Construct deposit model comprising of one or more of the following:
- Identification of five main sediment stratigraphic units
- Representative cross-sections across the deposit model study area
- Late Devensian and Holocene palaeolandsurface

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives
- No specific ground truthing undertaken
- Thick deposit of alluvium identified on areas of basal gravel topography
- Significant deposits of peat identified, some within palaeochannel fill sequences

Revise final product
New data will be added to the model as it becomes available, before final publication

Archive and reuse
The deposit model database is hosted within Quest and the model will be used as background data on any further developments within this area that Quest is commissioned to work on

11. The Battersea Channel Project: geoarchaeological deposit modelling as a unifying and dynamic resource for historic environment mitigation and dissemination

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Abstract

Multiple small and large-scale developments in the Nine Elms area of south-west London motivated Historic England to form the Battersea Channel Project (BCP). The Battersea Channel, now absent from the modern landscape, once formed part of the Late-glacial to early Holocene multi-channel braided network of the Thames. It was separated from the main channel by the Battersea Eyot, a relic island feature also not obvious in the modern topography. The intensive development around Nine Elms encompassed the entire eastern part of the area, which had previously received little attention, but was deemed to have the potential to preserve significant archaeological and palaeoenvironmental resources. A significant portion of the ongoing work, supported by the major partners (Historic England, MOLA, Quest and Wessex Archaeology), has focused on the construction of large-scale deposit models. As a result of this initiative, these major archaeological units, practitioners and curators have used the results of deposit modelling to target more effectively archaeological significant layers and to consider issues of preservation and geoprospection during planning and evaluation phases of construction. As the project progresses, partner and stakeholder involvement has been shown to significantly improve deposit modelling methodologies, data interpretation and presentation. The future benefits for the BCP in use, interpretation and dissemination of deposit modelling data are described and discussed, and a future for deposit modelling and landscape visualisation as a dynamic canvas for the integration and dissemination of archaeological knowledge is proposed.

11.1. Introduction

Over the last few years, the Nine Elms area of south-west London has become the focus of intense and widespread redevelopment, with up to 20 new construction/regeneration projects either finished or in the process of completion; many of these projects have either been attracted by, or are associated with, iconic sites such as the former Battersea Power Station and New Covent Garden Market, or new developments such as the relocation of the United States Embassy and Northern Line Extension. The Nine Elms area includes a landform feature known as the Battersea Channel, which once formed part of the Late-glacial to early Holocene multi-channel braided network of the Thames and is separated from the modern course of the river by the Battersea Eyot (Figure 11.1). In contrast to the modern foreshore of the river, where considerable Mesolithic to Iron Age evidence has been recorded, only sparse archaeological records existed for the wider Battersea Channel area prior to redevelopment of the Nine Elms area. Therefore, these multiple construction projects, particularly in the eastern part of the area, provided a significant opportunity to investigate the archaeological and palaeoenvironmental resource of the Thames floodplain and to record evidence of human occupation in the area (see also Payne *et al* Chapter 7 this volume for discussion of the New Covent Garden Market site).

As the geoarchaeological projects accompanying these construction schemes were being undertaken by a number of archaeological units and practitioners with input from a variety of curatorial officers, Historic England created an umbrella forum known as the Battersea Channel Project (BCP). The aim of this grouping was to bring together

Comparative data table of this deposit model	
Deposit model location	London, UK (NGR: 529900 177400)
Depositional environment	Floodplain sequence of the Battersea Channel: a Late-glacial and early Holocene landform of the River Thames
Size of deposit model	The deposit model covered a study area of c 200Ha
Data collection strategies	A mixture of geotechnical and purposive test pits, window samples and CPT boreholes, augmented by ongoing archaeological watching briefs and evaluation trenching providing additional sedimentological descriptions
Position in the archaeological process	The Battersea Channel Project provides an umbrella structure for multiple projects at various stages from pre-planning through to post-excavation analysis and publication
Reason for deposit model construction	1. To model the interface of the Pleistocene sediments (gravels) and the overlying Holocene sequence and to identify the major stratigraphic units in order to investigate the character and define the position of the Battersea Channel 2. To use the model to assess archaeological potential and to place discoveries within a secure landscape context
Archaeological question	To bring together archaeological and palaeoenvironmental information from multiple development sites in order to investigate the archaeological record of the Battersea Channel
Software and modelling process	The data was collated and sorted in Rockworks 15, with surfaces of key stratigraphic units modelled in ArcGIS 10.2 and 10.3. Representative stratigraphic transects were compiled in Rockworks 15 and were illustrated using Corel Draw and Illustrator
Outputs from the deposit model	Ongoing work as part of this study includes a series of topographically modelled surfaces, peat density maps and representative cross-sections. However, it is hoped that the raw data will form part of a limited but dynamic resource for use by curators, archaeologists, clients and the public

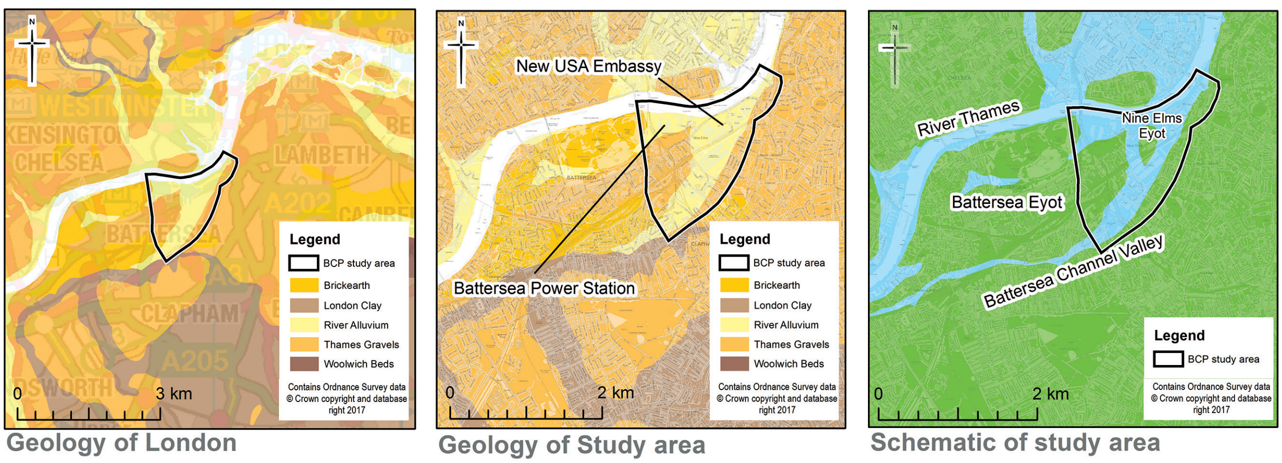


Figure 11.1: Location of Battersea Channel, wider Nine Elm's study area and surficial geology

representatives of Historic England, MOLA, Quest and Wessex Archaeology to share knowledge of ongoing and unpublished projects in order to target more effectively archaeological investigations and to aid the interpretation of findings with respect to the threatened heritage resource in the area.

11.2. Aims and objectives

Deposit modelling played a key role in the advancement of several of the project's specific research aims. Digital Elevation Models (DEM) interpolating the upper surface of the Pleistocene deposits (primarily gravels) provided a landscape template for study of the early Holocene palaeotopography, and enabled investigation of the location, orientation, size and depth of the channels that may have developed within the Battersea Channel landform.

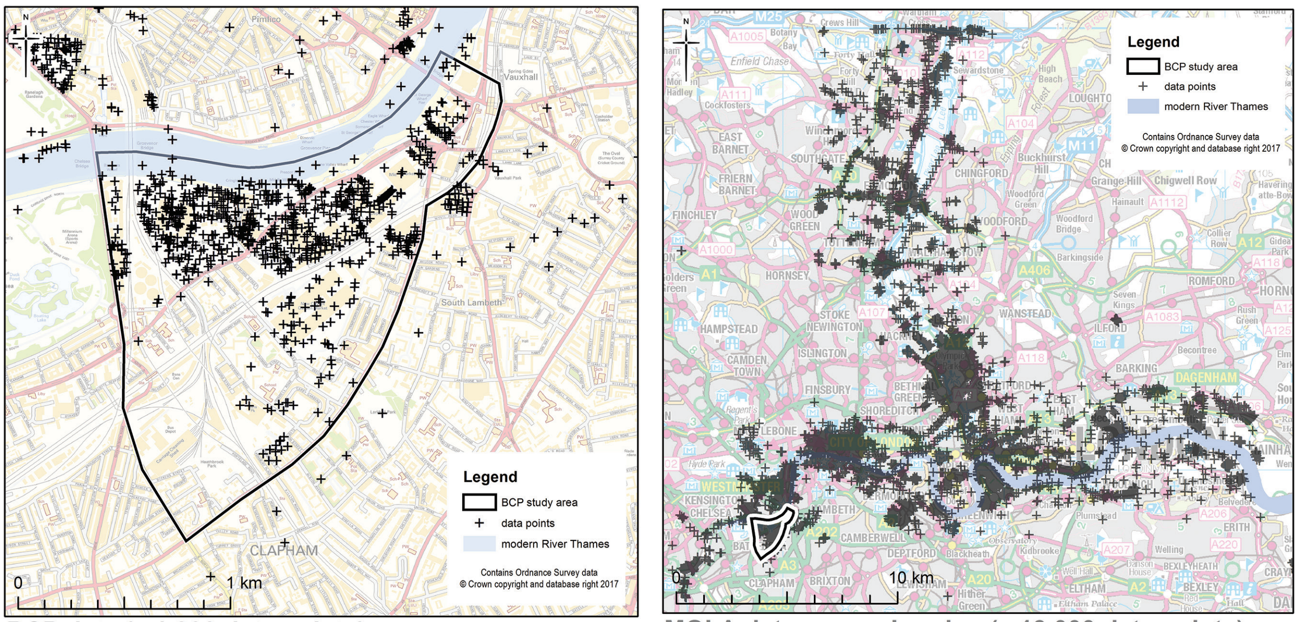
The early Holocene topography DEM (in conjunction with cross-sections showing the character of the overlying deposits) was used to investigate how the Battersea Channel and its internal smaller landforms (subsidiary channels, islands etc) shaped the prehistoric landscape and how the natural environment responded to changes in relative sea-level and associated tidal processes. Palaeoenvironmental evidence provided by botanical and faunal remains recovered from secure stratigraphic contexts afforded an opportunity to consider the scale and complexity of both natural environmental change and the impacts of human activity. With past landscapes reconstructed, the topographic and environmental models provided a framework to consider how contemporary human populations would have experienced, reacted to and shaped environmental change. Finally, beyond the specific aims and objectives relating to individual projects, an overarching aim of the BCP was to encourage close co-operation between different archaeological units, practitioners, and curators. This required the dovetailing and harmonisation of methodologies, philosophies and systems in order that knowledge and data could be usefully and rapidly shared. In this way, deposit modelling assumed a pivotal role in the sharing of data and discussion of the results of field investigations.

11.3. Methodology

Prior to inception of the BCP, MOLA's portion of the geoarchaeological dataset held for the Nine Elms area formed part of the MOLA Borehole Database, comprising over 11,000 separate entries compiled during work undertaken as an element of major MOLA initiatives such as the Lea Valley Mapping Project, investigations of the 2012 Olympic site and extensive work in the City of London, Westminster and Southwark (Figure 11.2). The entire BCP database consists of over 1,100 separate entries (590 provided by MOLA, 429 provided by Wessex Archaeology and 288 by Quest) relating to both historic and modern geotechnical and archaeological records.

Whilst the database may appear large for a relatively small area, it is important to be aware of both the key advantages and disadvantages of the different data sources and methodologies used (Table 11.1).

Since the deposit models constructed from the datasets described in Table 11.1 are part of ongoing geoarchaeological work, some areas investigated under the auspices of the BCP are only represented by a



BCP data (c 1,300 data points)

MOLA data across London (c 13,000 data points)

Figure 11.2: Data points within the wider MOLA Borehole Database and within the Battersea Channel Project area

Table 11.1: Summary of advantages and disadvantages of key source data

Source or method (proportion of the BCP database)	Advantage	Disadvantage
Historic British Geological Survey (BGS) and other geotechnical data (20% of MOLA BCP)	Large number of records available at no cost	Holocene deposit descriptions can be superficial and may not be sufficiently detailed to answer geoarchaeological questions
Geoarchaeological logs interpreted from monitored geotechnical interventions (boreholes and trial pits; estimated 60% of MOLA BCP)	Log descriptions are sufficiently detailed for geoarchaeological investigations	Interventions are not always continued to full depth (ie to bedrock/natural), may be disturbed or incomplete, or may not coincide with the most desirable sample location due to geotechnical drilling priorities
Geoarchaeological logs from purposive geoarchaeological interventions (boreholes and trial pits; estimated 15% of MOLA BCP)	Log descriptions are compiled specifically for geoarchaeological investigations and use tailored drilling methodologies aimed at applying the most effective sampling strategy and obtaining bespoke stratigraphic descriptions.	Can be prohibitively expensive for some developments
Archaeological trench sections (estimated 5% of MOLA BCP)	Associated with archaeologically significant layers such as old ground surfaces. More extensive exposures provide significant information on stratigraphy and sediment architecture	Stratigraphic records compiled during earlier investigations may not provide sufficiently detailed or comprehensive descriptions to answer geoarchaeological questions

sparse selection of database entries relating to historic geotechnical records; in contrast, other areas benefit from higher frequency and well-distributed geoarchaeological data, together with detailed archaeological records acquired through fieldwork campaigns. The ongoing approach, with regular updates and data-sharing between BCP partners, should allow investigation strategies for the various developments to adapt and target areas where data entries are sparse or inconclusive. It may benefit future statements of confidence in a deposit model if a standardised method for describing the distribution of both known and potential remains of archaeological significance is included; at present in MOLA, we are investigating whether the application of K function (Dixon 2006), spatial autocorrelation (Chatfield 2006) or hot spot analysis (Patil 2013) can provide an objective and appropriate way to quantifying the risk and validity of the model.

Rockworks 15 is being used for digital storage of geotechnical and geoarchaeological sediment log records and to create the basic profiles and transects for interpretation. In addition, illustrations for reports and publications are finessed with the aid of programs such as Adobe Illustrator and Corel Draw. The Spatial Analyst module, and in particular the Inverse Distance Weighted (IDW) tool of ArcGIS 10.3.1, is being used to create DEMs, while ArcScene 10.3.1 is being used to visualise these in 3-dimensions (see Jamieson in Corcoran *et al* 2011 for an extended discussion of the GIS tools used). MOLA is also developing the BCP's use of ArcGIS Online in order to share more freely data and deposit models with project partners.

A standard geoarchaeological approach was adapted for both research and commercial requirements, employing the following methodology:

- For all MOLA modelling projects, deposit description logs are inputted to the MOLA database. Discrete stratigraphic units are identified using pre-defined lithologies; these are generally defined by a capitalised primary component and a secondary lower case component (eg SAND, silty);
- The only pre-defined stratigraphy is a zero thickness unit denoting the early Holocene surface. MOLA GIS Toolbox was used in the construction of an early Holocene palaeotopographic DEM and thickness plots;

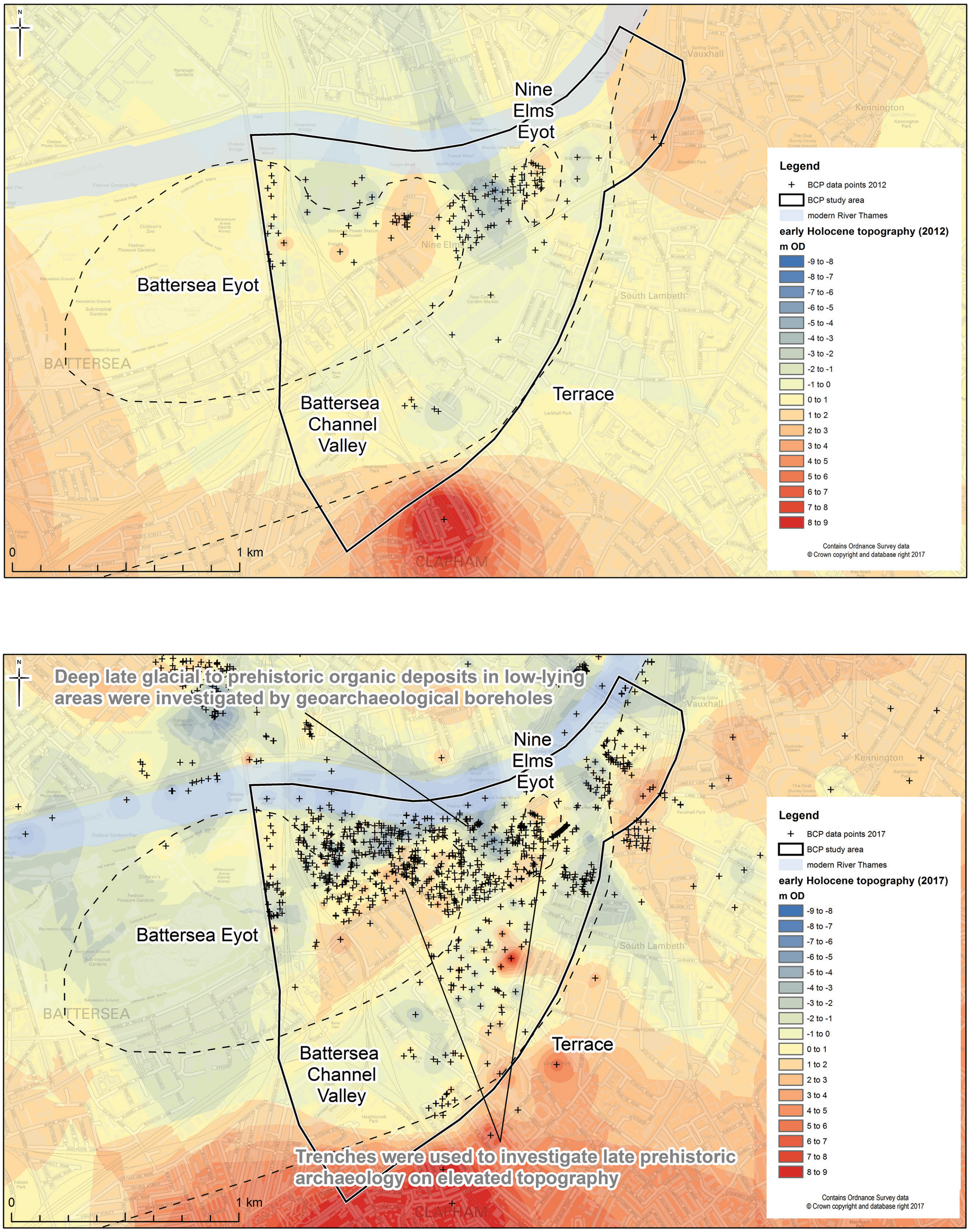


Figure 11.3: Comparison of (a) preliminary 2012 modelled early Holocene topography and (b) ongoing modelled early Holocene topography, from 2017, after initial targeted archaeological works

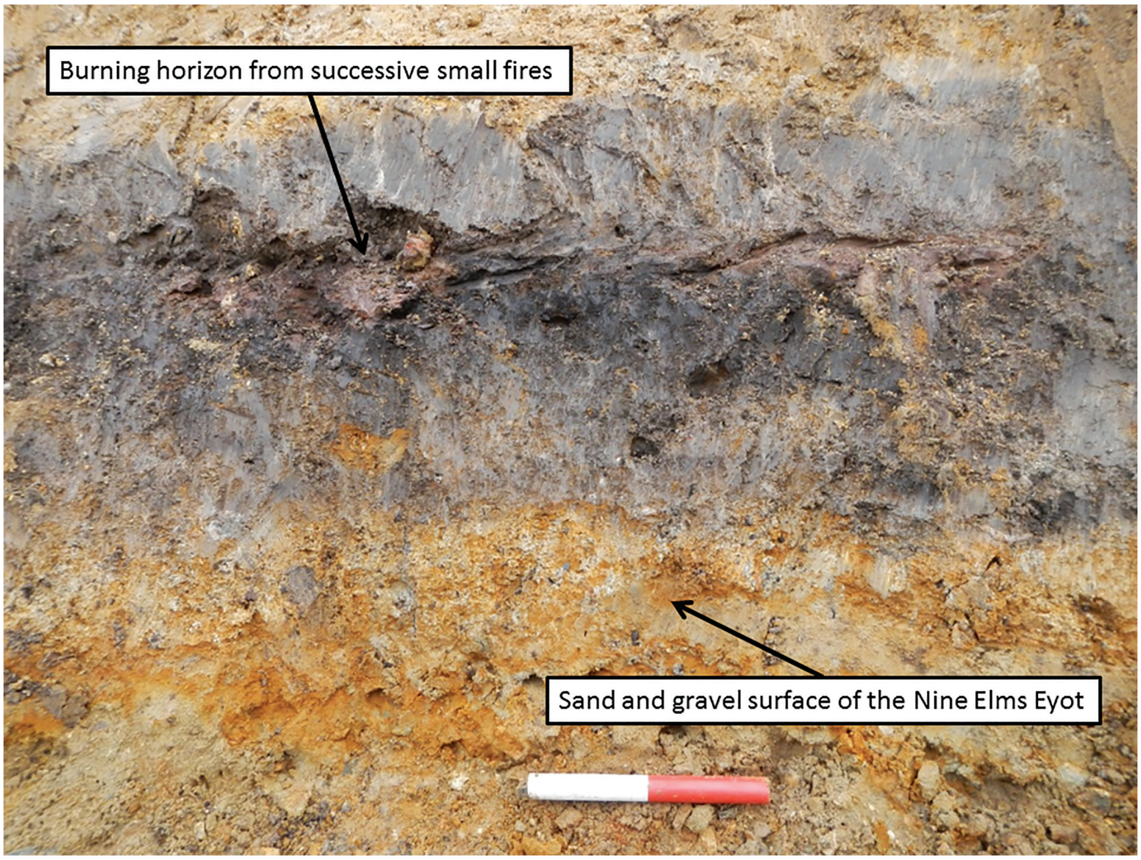


Figure 11.4: Photographs of archaeological evidence found within the study area (a) burning horizon found on the surface of the Nine Elms Eyot, on the new US Embassy site, representing prehistoric hearths, with micromorphological evidence of multiple phases of burning and associated Brown Bear remains; and (b) a Mesolithic timber piles on the Thames foreshore within the study area, radiocarbon dated between 4790 and 4540 BC (Thames Discovery Program)

- Transects were constructed and landscape zones identified, aiding thereby integration into the model of other sources of information (eg palaeoenvironmental, dating and archaeological evidence). The entire dataset provided a platform for data synthesis, geoprospection and interpretation.

It was foreseen that database terminology could become a significant issue as the BCP progressed. Lithological classifications and descriptions were broadly consistent across project partners, but stratigraphy varied significantly between sites in response to the complexity of taphonomic processes. Many of the inter-site differences could be accommodated automatically in Rockworks or resolved during the collation of Excel spreadsheets. However, the biggest methodological challenge of the BCP was the creation of systems capable of generating outputs which aided productive synthesis and debate between partners. The problem was compounded by the fact that participants needed to consider ongoing work on adjacent sites that were separately funded, employed different archaeological units and were at different stages of the archaeological planning process.

11.4. Preliminary interpretation and use of the deposit model

Precursors to the BCP model and the model itself have been used at various stages in the planning process to aid archaeological understanding of several different developments. The Battersea Channel was highlighted as a feature of archaeological and palaeoenvironmental interest by deposit modelling undertaken by MOLA at Stewart's Road back in 2009 (Morley 2009). However, by focusing initially on its use at the pre-fieldwork or pre-evaluation stage, the early models lacked detail. These earlier models (based on historic data or monitored geotechnical works; MOLA 2012) were used to highlight areas of archaeological or geoarchaeological potential based on different fieldwork approaches (Figure 11.3). The areas of higher ground were targeted mainly for evaluation trenching and watching briefs. On the Nine Elms Eyot, for example, within the new United States Embassy development, a watching brief successfully recorded burnt horizons, which were interpreted as the remains of prehistoric hearths; these were associated with faunal remains of Brown Bear (Figure 11.4) and were found close to the degraded remains of a small wooden structure (MOLA 2015). Large palaeochannels, in the low-lying parts of the floodplain were targeted for palaeoenvironmental investigation using less invasive window sample surveys; these yielded organic deposits radiocarbon-dated to important periods of climatic transition over the Late-glacial (Windermere Interstadial) and early Mesolithic periods (MOLA 2015). In addition, aligned timber stakes (as yet undated) and Iron Age pottery have been identified on the buried Thames foreshore of the Battersea Eyot at Battersea Power Station (Richard Meager, CgMS: pers. comm.), at the same location as previous finds of timber structures (Figure 11.4; Elliot Wragg, Thames Discovery Programme: pers. comm.).

Grey literature reports, predominantly geoarchaeological in focus, describe these preliminary findings for the separate developments of the BCP and present 2-dimensional updates of the early Holocene topography (DEM formats) and associated stratigraphy (cross-section or DEM formats). Regular BCP meetings inform all the partners of significant archaeological finds and the raw subsurface data, and deposit models are shared digitally and combined into the full BCP database. This ongoing process allows pre-fieldwork, evaluation and assessment findings to feed back into the deposit model, thus allowing strategies to be revised more dynamically. Deposit models are well suited as the front ends of databases integrating specialist chronostratigraphic, palaeoenvironmental, geological and archaeological information, and provide excellent tools for communicating widely the changing interactions of human communities with their environment. This approach should permit continual refinement of strategies and priorities and contribute to the creation of a final publication and other dissemination products that are closely integrated and widely accessible.

11.5. Conclusions

All MOLA geoarchaeological work that has been undertaken over the last decade has become part of an evolving MOLA borehole database, providing thereby a wider context for landscape reconstructions. However, the use of this resource is predominantly restricted to MOLA personnel, as it is generally regarded as a commercial asset containing confidential data for active projects. These issues notwithstanding, MOLA is now sharing more data than ever before, and it is hoped that the BCP database will become more widely accessible in the future. Despite inherent problems within archaeological practice, especially in urban environments where experience has demonstrated that data may be incomplete or highly dispersed, deposit modelling remains an important investigative and explanatory tool. The distribution and reliability of data and the derived models must, however, be fully discussed, and in this respect the discussions and reflections about issues of accuracy and methodological rigor that have been encouraged by the BCP represent significant achievements. Hopefully, such an integrated and overarching approach will minimise shortfalls and improve methods, although even the BCP lacks a truly centralised dynamic resource; data integration is therefore slower and more difficult than it could be, which has significant implications for ongoing data capture and data dissemination between partners. As part of the ongoing BCP, MOLA is working towards the use of ArcGIS Online to share raw data, DEMs and models in something approaching a dynamic resource, but this may only be fully realised at the final stages of the BCP.

For curators and project designers, the construction of simple and accessible overarching deposit models like that described here means that appropriate strategies can be developed to assess and mitigate the threats to archaeological remains. If these deposit models are digitally integrated with the wider archaeological knowledge base, then curators will be better informed about the potential resource and opportunities to address both regional and national research priorities. All archaeological units involved in work in the BCP study area become part of the project and benefit from access to the project's shared knowledge and the interaction between project partners; this in turn can forge stronger links between participating organisations that will reap wider benefits.

Many archaeological practitioners have emphasised to clients the benefits of deposit modelling as a cost-effective means of mitigating the threats to the preserved archaeological and palaeoenvironmental resource. By ensuring that the financial and programming advantages of focusing investigations upon key areas of sites impacted by construction work are widely understood, many London developers now understand the benefits of commissioning approaches that include deposit modelling.

Basic deposit modelling is relatively cheap, with clear planning benefits to all, and it is hoped that the BCP will show that GIS modelling has a greater potential to integrate and convey archaeological findings under broader research and engagement themes than it presently does. The behind-the-scenes nature of this type of work, in contrast to the more visible benefits of archaeological excavation, puts the onus on the practitioners of deposit modelling to show what impact such work can truly have. Engaging the wider public with environmental and landscape histories can be more difficult, but the Museum of London's 'Street Museum' app has shown that using digital datasets in an innovative way can prove popular; this phone app allows users to view historic images of London streets using geospatial information, including real-time GPS data. More complex integrated systems, with landscape as the framework, can be migrated easily to simplified online resources where landscape represents the visual pivot around which modern communities can experience and learn the heritage story of where they live and work. Whilst major infrastructure projects such as Crossrail and the regeneration of parts of east London for the 2012 Olympics have investigated large areas and many different types and periods of archaeological interest, it can be difficult to collate coherently such a broad corpus of information for publication. Such large-scale projects could benefit significantly from the heritage integration and narrative capabilities of landscape-based systems such as ESRI's Story Maps (https://storymaps.arcgis.com/en/). Story maps have the potential to demonstrate to the local community and wider public the benefits of clients' development as well as updating heritage colleagues on the results of specific site investigations. With appropriate investment, individuals might even be able to access a Story Map about a new development on their phones or, in the future, see a virtual past landscape using low-cost equipment such as Google Cardboard (https://vr.google.com/cardboard/).

There is a bright future for deposit modelling if innovation continues, but without more centralised and dynamic resource coordination the current *status quo* may continue. In such a scenario, commercially advantageous resources (collected by single organisations or through one-off multi-partner collaborations) cease to be dynamic or even accessible beyond the financial limits of a project. It is hoped that the BCP will be a decisive first-step towards a better future for deposit modelling.

Acknowledgements

The author would like to extend particular thanks to Mark Stevenson of Historic England for spearheading the Battersea Channel Project and to Stewart Hoad for project management of BCP activities within MOLA. In addition, BCP deposit modelling would not have been possible without the significant input and partnership of Rob Batchelor (Quest) and David Norcott (Wessex Archaeology), as well as the other BCP partners.

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Constructing a geoarchaeological deposit model: Battersea Channel Project

↓

Assess pre-existing data

- British Geological Survey boreholes
- Geoarchaeological and geotechnical logs held by MOLA, including boreholes and test pits
- Archaeological trench sections from archived data

↓

Develop rationale for model construction and key aims and objectives

- To model the interface of the Pleistocene sediments and overlying Holocene sediments
- Identify major sediment stratigraphic units
- Define archaeological potential
- Identify the position of the Battersea Channel
- Provide an umbrella structure for multiple projects in the area that have potential to impact on archaeological resources

↓

Can the deposit model be constructed using pre-existing data?

Yes, the project is utilising data from multiple archaeological partner organisations, sharing data through the Battersea Channel Project

↓

Commission further ground investigations, including:

- Additional purposive boreholes and recording of geotechnical boreholes and test pits on new development plots to add more data into the evolving model

↓

Construct deposit model comprising of one or more of the following:

- Provide an early Holocene Digital Elevation Model
- Interpolation of key macro-stratigraphic sediment units, particular organic Holocene deposits and palaeochannel sequences
- Representative cross-sections across the development areas

↓

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- Multiple archaeological investigations in different development plots
- Significant archaeological remains found on the Nine Elms Eyot, with significant palaeochannel deposits located within the lower floodplain and timber stakes at the Battersea Power Station

↓

Revise final product

The deposit model is continually having information added to it through the Battersea Channel Project database

↓

Archive and reuse

The database is continually being added to and forms part of the MOLA database archive, with Battersea Channel data being shared across multiple partner organisations

SECTION 6

Modelling as an aid to post-excavation analysis

12. Medmerry Managed Realignment Scheme, West Sussex: a Holocene deposit model of a coastal environment

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Abstract

An Environment Agency funded managed coastline realignment scheme was completed at Medmerry, West Sussex in 2013. The construction of a perimeter bund necessitated the extraction of material from within the scheme and afforded an opportunity to investigate both the archaeological and palaeoenvironmental remains and the landscape evolution of the area. The site is located to the west of Selsey Bill on the Manhood Peninsula and has long been known to preserve important Quaternary sedimentary archives. There has, however, been little targeted work prior to this project to investigate these deposits, particularly with reference to the Holocene record.

In order to characterise the landscape evolution of the site, a programme of hand auger survey and palaeoenvironmental analysis was carried out. During the post-excavation phase of the project, the deposits recorded at the site were modelled using both ArcGIS and Rockworks to aid in the visualisation of the sequences investigated. This modelling demonstrated the presence of a deeply buried Late Mesolithic-Early Neolithic peat deposit indicative of a former freshwater wetland. This was replaced by a large protected lagoon during the Late Neolithic-Middle Bronze Age. The models facilitated interpretations of the archaeological and environmental data gathered during the project and were also used as part of the outreach programme and ongoing monitoring of the site by local volunteer Heritage groups.

12.1. Introduction

The site of Medmerry is located on the Manhood Peninsula to the west of Selsey Bill at the tip of the West Sussex Coastal Plain, a low-lying area which stretches for 16km from the foot of the South Downs (Figure 12.1). The Peninsula has long been recognised as having the potential to preserve important Quaternary sedimentary sequences and associated archaeological remains of both Pleistocene and Holocene age (Bates *et al* 2009; Bone 1996; Bone and Tracey 1996).

In recent years the area has suffered from increasing storm frequency and magnitude, which have had a detrimental effect on the livelihood of the local residents. In 2008, the Bunn Leisure Caravan Park and surrounding agricultural land were inundated by floodwaters, causing widespread damage. Consequently, between 2009 and 2013 the Environment Agency undertook a managed realignment scheme. This was a soft-engineered scheme which involved the construction of a 7km long perimeter flood bank designed to store floodwaters and absorb better the impact of future storm events. As a result of the construction works, the scheme created a wetland nature reserve to meet Environment Agency requirements for compensatory habitat under the Habitat and Species Regulations 2010 (http://www.legislation.gov.uk/uksi/2010/490/contents/made); the reserve is now under the management of the Royal Society for the Protection of Birds (RSPB). The scheme covered 300ha and, as part of the works, a programme of archaeological investigation was undertaken. In parallel, geoarchaeological investigations were also carried out. Since the area had received little previous attention and lacked pre-existing geotechnical information, the work included targeted hand auger survey, palaeoenvironmental sampling and analysis. The resulting data was incorporated into a deposit model during the post-excavation process, using both ArcGIS and Rockworks.

12.2. Aims and objectives

Deposit modelling was utilised as a post-excavation visualisation tool. The lack of any previous data from the

Comparative data table of this deposit model	
Deposit model location	Medmerry, West Sussex, UK (NGR: 483469 095339)
Depositional environment	Holocene freshwater wetland and brackish lagoon
Size of deposit model	Development area of *c* 300Ha; 182Ha of intertidal habitat created
Data collection strategies	Hand auger survey in an area with no existing borehole data for investigating sediments with archaeological and palaeoenvironmental potential
Position in the archaeological process	Model was undertaken after fieldwork was completed as part of the post-excavation analysis
Reason for deposit model construction	To understand the subsurface topography and distribution of sediments in order to characterise better the Holocene palaeogeography of the Manhood Peninsula
Archaeological question	How to reconcile the palaeoenvironmental data with the historical understanding of the development of the Manhood Peninsula
Software and modelling process	The sediments were entered into a Rockworks database to create 2-dimensional and 3-dimensional models of the subsurface topography. Surfaces were also created in ArcGIS
Outputs from the deposit model	A series of images to aid visualisation were exported as jpegs for inclusion in the final publication. In addition, a Rockworks database was created which will be included as part of the site archive

area relating to Holocene coastal development highlighted the importance of representing the sediments in an easily accessible and interpretable format. Therefore, the principle objectives of the deposit modelling were to:

- Record the stratigraphic sequence of deposits to allow the creation of a visual representation of the subsurface sediment architecture;
- Enhance understanding of the sequence of deposits in relation to the modern coastal configuration;
- Integrate within the model the results of palaeoenvironmental analysis.

The modelling and analysis of deposits at the site was intended to demonstrate its research potential and to identify historic environment themes for further study. It was also conducted with the aim of enhancing the corpus of research focused on low cost, low impact methodological approaches to the recovery of geoarchaeological information from complex and deeply buried sedimentary sequences.

12.3. Methodology

The lack of existing geotechnical data for the site and of previous targeted investigations prevented modelling prior to the commencement of fieldwork. The site was divided into areas of historic environment impact, which comprised three large borrow pits for the extraction of bund material (BP8, 10 and 11). The underlying superficial Quaternary geology of the site, as mapped by the British Geological Survey (BGS), comprised Raised Marine Deposits, River Terrace Deposits, Raised Beach Deposits, Head, and Beach Tidal Flat Deposits. The solid geology is characterised by the Selsey Sand Formation and Marsh Farm Formation of the (Eocene) Bracklesham Group.

The significant size of the managed realignment scheme at Medmerry was such that the survey was confined either to areas that were accessible during the archaeological excavations (BP8 and BP11) or to areas that had already been stripped by machine (eg BI1, where highly oxidised silts overlay peat deposits; Figure 12.2). A rapid hand auger survey was carried out first with the aim of focusing more effectively the collection of data; this led to the selection of BP8, BP11 and BI1 as the main areas for further investigation and survey of the subsurface stratigraphy. The deposits were investigated using an Eijelkamp gouge auger with a 1m long open chamber, and were sampled at a 5m spacing. The core locations were recorded with RTK GPS. The lithology was recorded using the Troels-Smith (1955) system of sediment classification, which characterises the sediments on a scale of 1-4 in terms of a number of criteria (Table 12.1):

In total, 169 cores were recorded across the three areas, with the majority focused on BP8 due to the presence of a large medieval fish weir (Figure 12.2). The

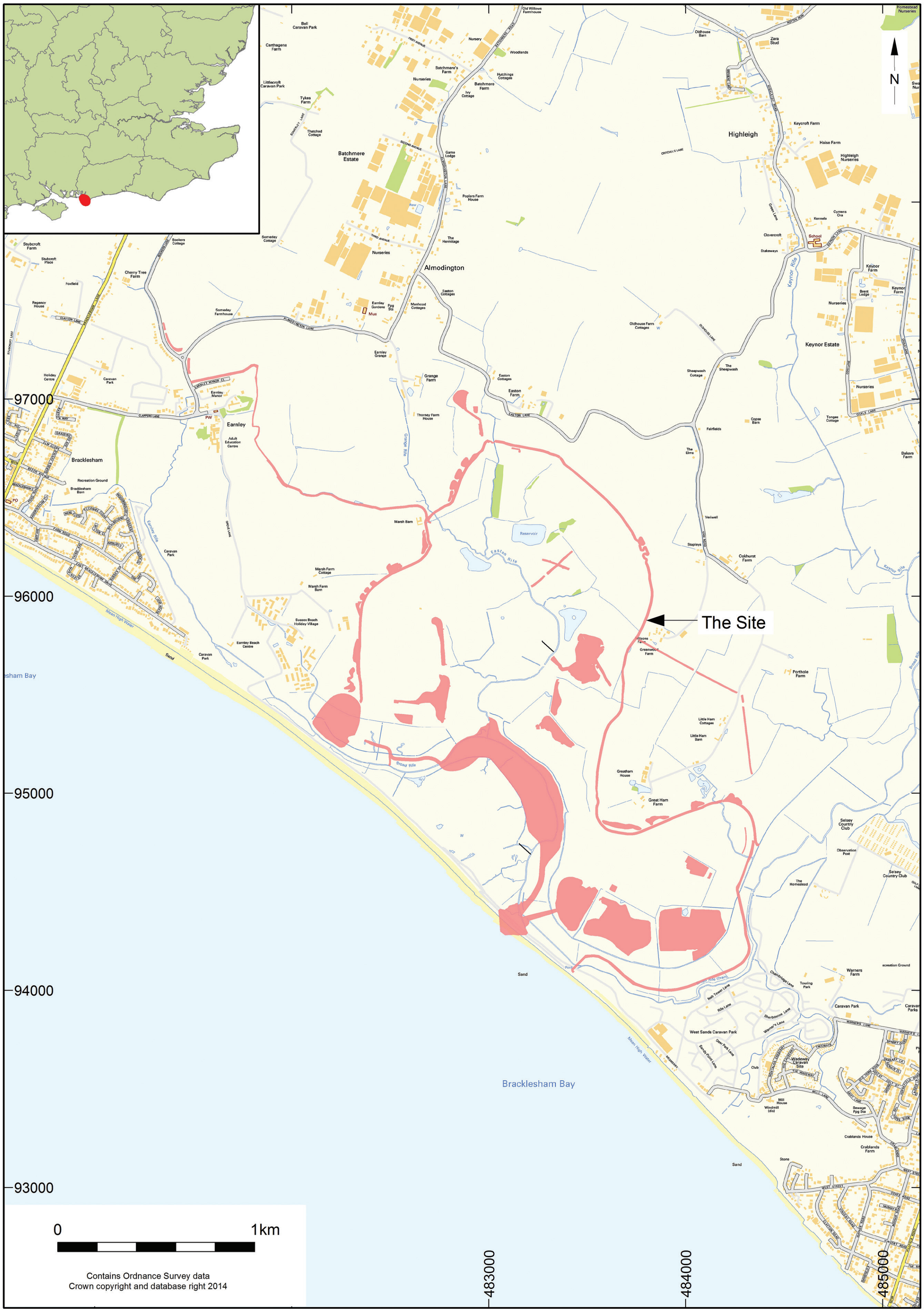

Figure 12.1: Medmerry Managed Realignment Scheme study area on the West Sussex Coastal Plain

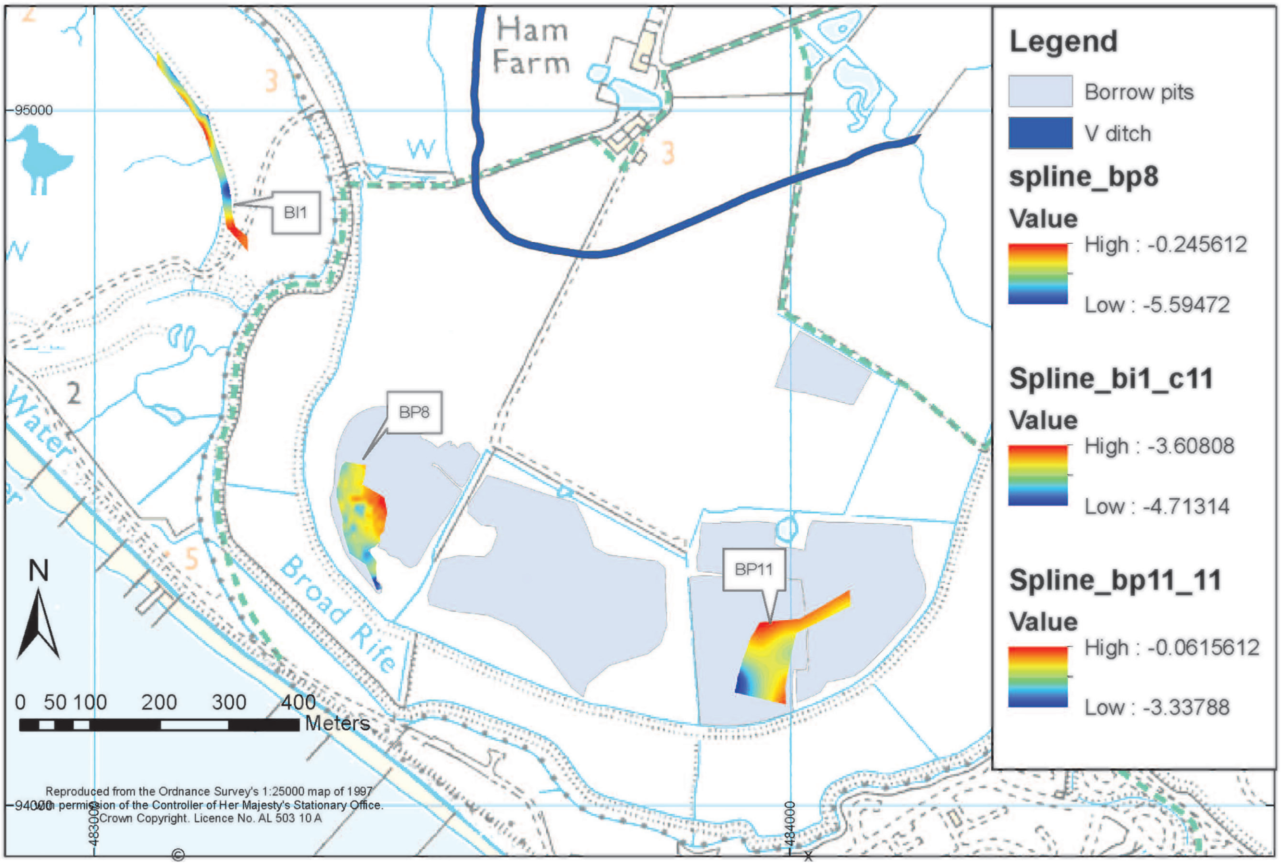

Figure 12.2: Key features of the Medmerry study area including borrow pits, perimeter V ditch and GIS surfaces in the areas of coring

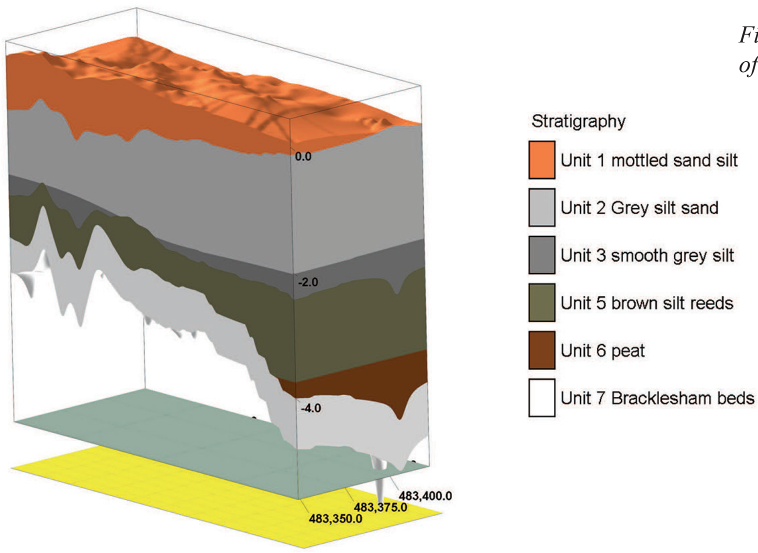

Figure 12.3: Deposit model of Borrow Pit 8

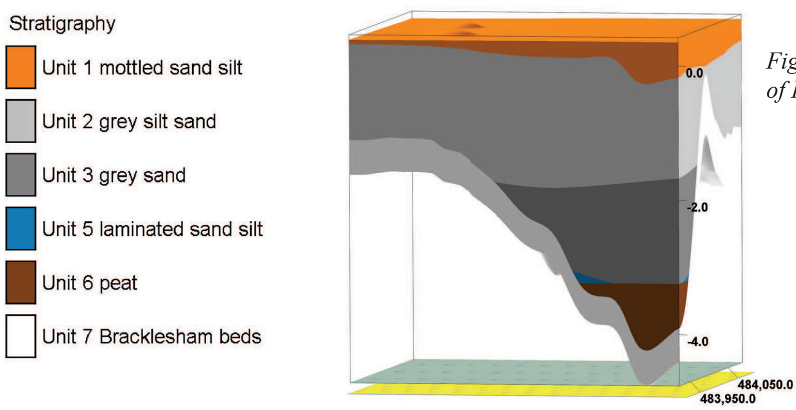

Figure 12.4: Deposit model of Borrow Pit 11

Table 12.1: Criteria of sedimentological assessment according to Troels-Smith

Degree of Darkness	
nig.4	black
nig.3	
nig.2	
nig.1	
nig.0	white

Degree of Stratification	
strf.4	well stratified
strf.3	
strf.2	
strf.1	
strf.0	no stratification

Degree of Elasticity	
elas.4	very elastic
elas.3	
elas.2	
elas.1	
elas.0	no elasticity

Degree of Dryness	
sicc.4	very dry
sicc.3	
sicc.2	
sicc.1	
sicc.0	water

	Sharpness of Upper Boundary
lim.4	< 0.5mm
lim.3	< 1.0 & > 0.5mm
lim.2	< 2.0 & > 1.0mm
lim.1	< 10.0 & > 2.0mm
lim.0	> 10.0mm

	Sh	*Substantia humosa*	Humous substance, homogeneous microscopic structure
I Turfa	*Tb*	*T. bryophytica*	Mosses +/- humous substance
	Tl	*T. lignosa*	Stumps, roots, intertwined rootlets, of ligneous plants
	Th	*T. herbacea*	Roots, intertwined rootlets, rhizomes of herbaceous plants
II Detritus	*Dl*	*D. lignosus*	Fragments of ligneous plants >2mm
	Dh	*D. herbosus*	Fragments of herbaceous plants >2mm
	Dg	*D. granosus*	Fragments of ligneous and herbaceous plants <2mm >0.1mm
III Limus	*Lf*	*L. ferrugineus*	Rust, non-hardened. Particles <0.1mm
IV Argilla	*As*	*A.steatodes*	Particles of clay
	Ag	*A. granosa*	Particles of silt
V Grana	*Ga*	*G. arenosa*	Mineral particles 0.6 to 0.2mm
	Gs	*G. saburralia*	Mineral particles 2.0 to 0.6mm
	Gg(min)	*G. glareosa minora*	Mineral particles 6.0 to 2.0mm
	Gg(maj)	*G. glareosa majora*	Mineral particles 20.0 to 6.0mm
	Ptm	*Particulae testae molloscorum*	Fragments of calcareous shells

sediments were sampled in the field using kubiena tins and by taking bulk samples from open sections; the deeper sediments were extracted using a Russian auger, which recovered sediment in 0.50m lengths. These samples were submitted for multi-proxy palaeoenvironmental study, including analyses of pollen, diatoms, ostracods, foraminifera, insects and plant macrofossils. In addition, age determinations were recovered from organic samples using radiocarbon dating; the results were refined further by using Bayesian analysis, which seeks to increase the accuracy and precision of chronologies (Bronk Ramsey 2009).

The lithological data was divided into stratigraphic units on the grounds of similarities in the sedimentary characteristics. The thickness and height (altitude) of the upper and lower bounding surfaces of key stratigraphic units were inputted initially into spreadsheets to provide data for the creation of a series of surfaces in ArcGIS 10 (Figure 12.2). These surfaces were interpolated using a tension spline, which smooths out topographic variations in the data. As post-excavation analysis progressed, the data was also modelled within Rockworks 16; this allowed solid 3-dimensional models (Figures 12.3 and 12.4), fence diagrams (Figure 12.5) and 2-dimensional cross-sections (Figure 12.6) to be produced. The data in Rockworks is stored within an Access database, which will form part of the site archive.

12.4. Interpretation

The auger survey demonstrated that across the three areas modelled a 0.2m thick peat horizon had accumulated above the solid geology (Figures 12.3 and 12.4**)**. This peat layer was overlain in BP8 and BP11 by a thick unit of (reed-rich) brown silt which, in turn, was overlain by a smooth grey silt (Figure 12.5 and 12.6) grading into an upper grey silt-sand up to 2m thick. At BI1, to the north-west of the site, the lower peat was overlain by a smooth, grey silt-clay, similar to that recorded in BP8 and BP11, but this silt unit graded into a laminated silt-clay sand (Figure 12.7). In all areas, thin, discontinuous layers of shell fragments were recorded (Figure 12.8).

The subsequent palaeoenvironmental and radiocarbon analyses demonstrated that the peat deposit at the base of the sequence dated to the Late Mesolithic-Early Neolithic period (5469 ± 31 BP; 4360–4260 cal. BC; SUERC-60632). The pollen assemblage indicated that the contemporary landscape was a freshwater wetland; the thin nature of the deposit suggests that the sample site may lie at the northern extreme of this wetland and that thicker deposits may be buried and preserved farther to the south of the site. However, the upper boundary of this unit was sharp, suggesting an erosional contact associated with marine transgression, which might also have removed an unknown amount of sediment. It is only by undertaking survey further south of the sampling site that this can be established. The microfossil assemblages that were recorded in the overlying silts demonstrate that this transgression led to the formation of a large protected, brackish lagoon similar to the contemporary Fleet Lagoon behind Chesil Beach (Dorset), approximately 125km west of Medmerry. The timing of this change from freshwater to brackish water environments has proved hard to establish with confidence, but it is likely to have occurred during the Late Neolithic to Middle Bronze Age period in keeping with regional models of sea level rise. The subsequent ostracod and foraminfera analyses of the shelly horizons suggest that they represent the remains of

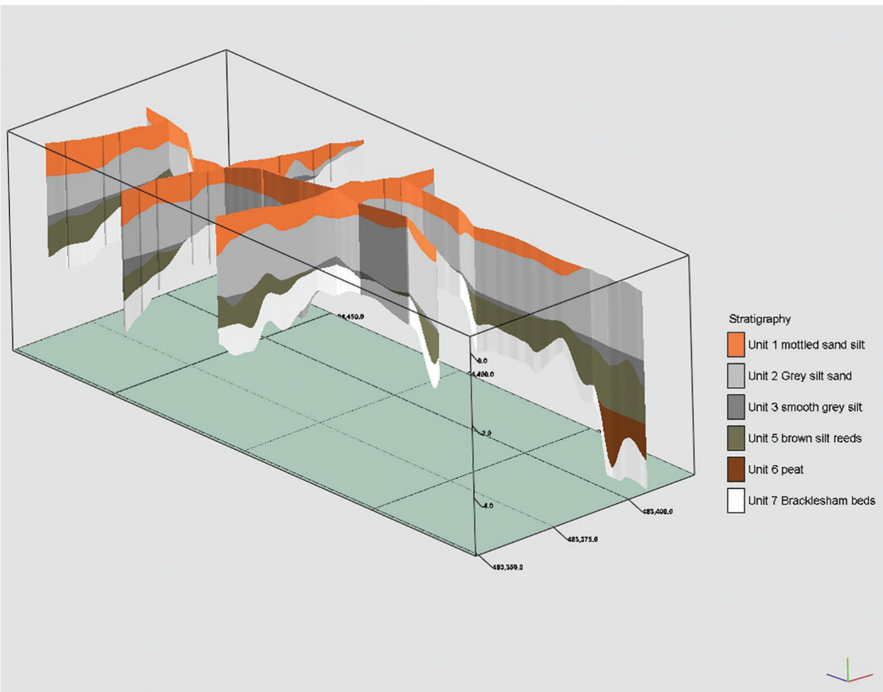

Figure 12.5: Fence diagram illustrating the 3-dimensional stratigraphy of Borrow Pit 8

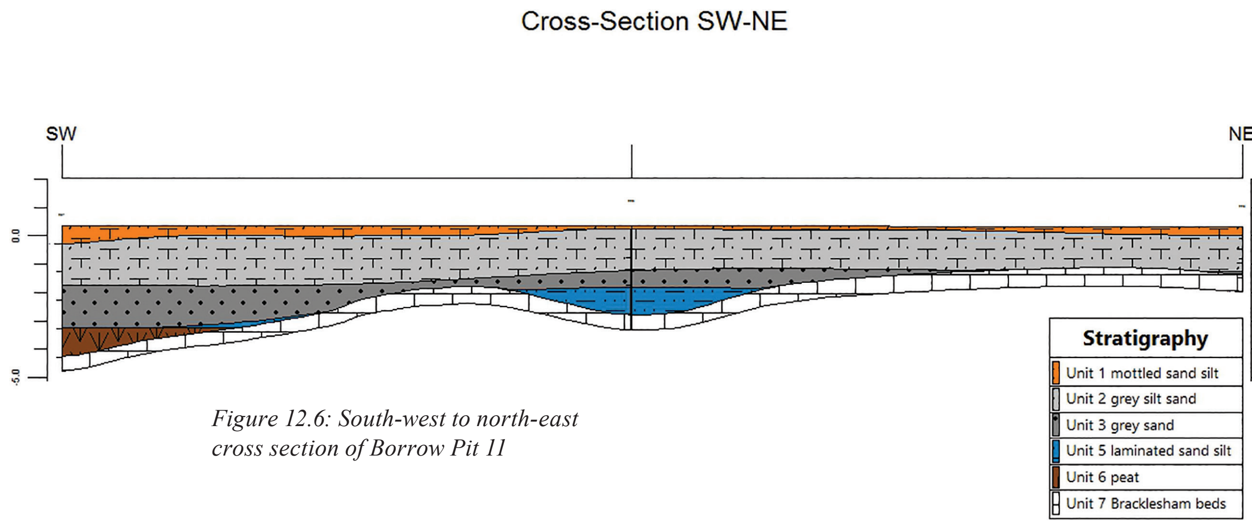

Figure 12.6: South-west to north-east cross section of Borrow Pit 11

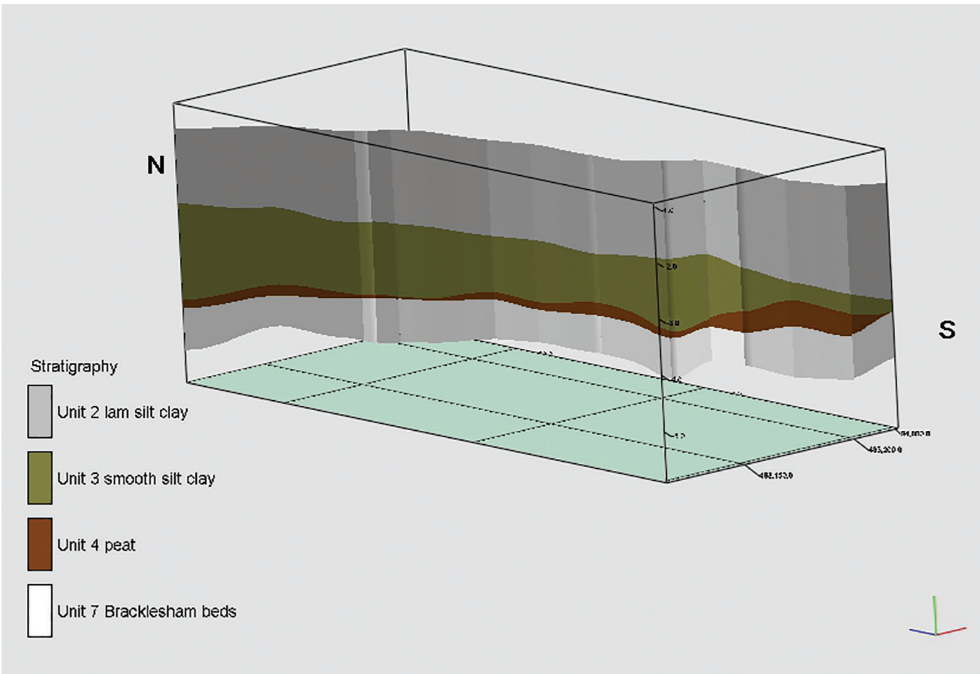

Figure 12.7: Fence diagram illustrating the 3-dimensional stratigraphy of Bird Island 1(BI1)

storm surge deposits; these are likely to have breached the shingle barriers that characterised the south coast in the Early-Middle Holocene (Long *et al* 2006).

The analysis of the deposits at Medmerry is by no means intended to create a definitive narrative for the evolution of the coastal zone, but has demonstrated that deposits survive at the site and have the potential for palaeoenvironmental reconstruction. The model has also allowed these deposits to be visualised in a way that aids interpretation and understanding of the palaeoenvironmental and archaeological data by both the archaeological community and other stakeholder groups.

12.5. Post-excavation analysis

The deposit model was used to build the narrative for the post-excavation publication (Stevenson 2014; Stevenson and Krawiec in prep). Moreover, as the data is in a digital format that can be exported as either a MS Access database or MS Excel spreadsheet, it can be utilised by other researchers. The models and analyses were intended as useful starting points for future research within the Medmerry area. In addition, it was hoped to provide baseline data that could be employed for comparison with other regional sequences and models as and when they are developed. The Medmerry data has been uploaded to the West Sussex Historic Environment Record (HER). The file sizes are relatively small, which will expedite the addition and storage of further data if this becomes available.

The model has also been used to challenge interpretations of landscape change which have become ingrained in the literature. The presence of a continuous navigable channel from Pagham to Selsey has long been suggested to have isolated Selsey Bill from the rest of the Manhood Peninsula (Wallace 1996, 205), but this is

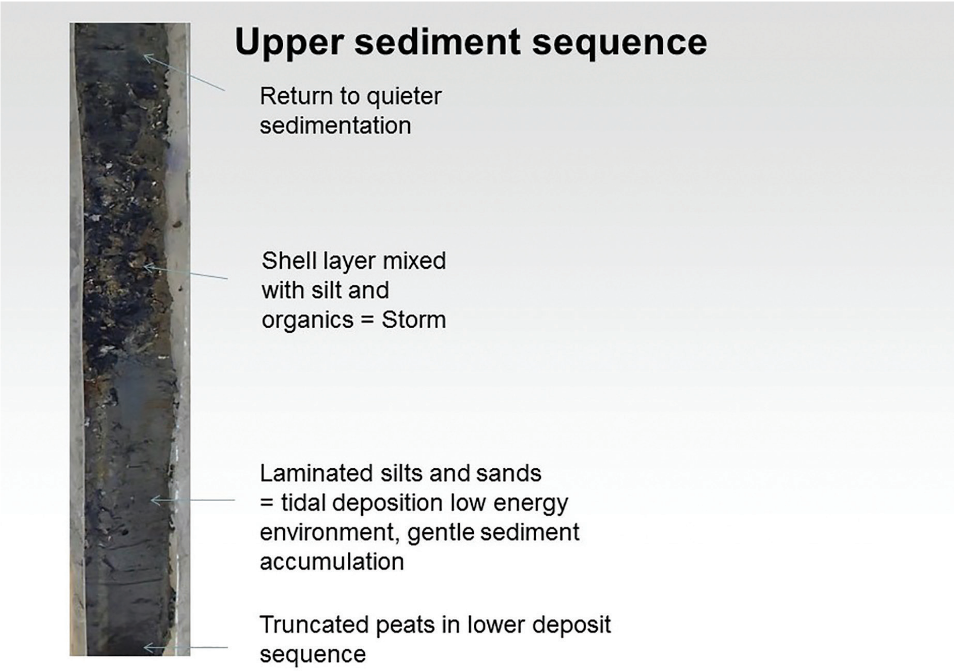

Figure 12.8: Plate illustrating thin, discontinuous shelly layers recorded during auger survey

not borne out by the evidence gathered in the field by Archaeology South-East during this project. In addition, the persistent theory of an Iron Age oppidum at the site (Cunliffe 2005, 172; Davenport 2003, 105; Wallace 1996) is unlikely in view of the lack of evidence for an inland channel and the formation of the lagoon behind a shingle barrier. The palaeoenvironmental evidence is supported in this respect by the results of archaeological investigations, which provide no evidence of high-status or dense Iron Age occupation at the site.

The deposit model has also been used to demonstrate the nature of the deposits within the Peninsula to a non-specialist audience. The continually eroding foreshore is currently being monitored by the Chichester District Archaeology Society, members of which participated in training events informed by the deposit model. The model has also been used to demonstrate the sometimes abstract concepts of landscape reconstruction and subsurface deposit modelling as part of the project's outreach programme.

12.6. Conclusions

The deposit model created for the Medmerry managed realignment scheme has demonstrated that palaeoenvironmentally significant deposits and interbedded archaeological remains survive at the site, despite past and present coastal erosion. In addition, the use of hand augering has demonstrated that the acquisition of data need not be prevented by costly field investigation.

The auger survey and archaeological investigations were carried out during the realignment works, which necessarily led to time-constraints in the field. The application of this methodology would ideally be carried out in advance of groundworks to allow more of the areas to be investigated. However, as the groundworks were already underway, valuable time was saved by the removal of the upper oxidised sediment within the borrow pit and ditch excavation areas; this facilitated targeted augering in areas where much of the dry sediment (which is time consuming to hand-auger through) above the peat had already been removed.

It is hoped that this model will allow further targeted investigations to be carried out on the Peninsula, enabling the collection of data that could be analysed with the aim of refining further the deposit model. From that perspective, it should be emphasised that the methodology that has been applied here as a post-excavation tool could be applied equally effectively to pre-application stage projects.

Acknowledgments

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Constructing a Georarchaeological Deposit Model: Medmerry

Assess Data Collected

- Identify sediment units
- Merge survey data

Rationale for model construction

- Visualise sediment distribution
- Identify common horizons
- Recognise changes in depositional environment

Can the DM be constructed using pre-existing data? yes

Construct deposit model comprising of one or more of the following:

- Cross-sections and fence diagrams
- 3D solid models
- 3D GIS surface

Relate model back to the rationale of aims and objectives:

- Sediments identified
- Recommendations for further research suggested

Revise final product

Deposit model integrated with palaeoenvironmental data

Archive and reuse

Raw data and reports archived with West Sussex HER

Monograph published

13. Geoarchaeological deposit modelling in the heart of London

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Abstract

Redevelopment in the City of London between 2010 and 2014 of the area of the Walbrook valley where the 3rd century AD temple of Mithras was discovered previously provided an opportunity to excavate the most extensive and significant Roman remains in the modern city for 20 years. The deeply buried nature of the site and deep urban stratigraphy required the design of an innovative mitigation strategy that included development of a geoarchaeological deposit model. Constructed in Rockworks and ArcGIS, the model used a combination of sedimentary descriptions transcribed from test pit and borehole records carried out for geotechnical and geoarchaeological purposes, as well as information from archaeological trenches. The deposit model made an important contribution to the project in providing a view of the pre-Roman landscape, interpretation of the prehistoric deposits and inferring the story of Holocene valley evolution, which provided the template for Roman occupation.

Comparative data table of this deposit model	
Deposit model location	City of London
Depositional environment	Urban
Size of deposit model	*c* 520 data points over *c* 600,000m^2 (60 ha)
Data collection strategies	Archaeological trenching, geoarchaeological and geotechnical borehole analysis and review of British Geological Survey records
Position in the archaeological process	Pre- to post-excavation
Reason for deposit model construction	To inform on archaeological potential, landscape reconstruction, deposit characterisation and interpretation
Archaeological question	To consider the distribution of archaeological remains and the palaeoenvironments coeval with such remains
Software and modelling process	RockWorks 15; ARCGIS 10.1
Outputs from the deposit model	Models illustrating thickness and palaeotopography of key units and palaeolandsurfaces. Images for use in reports, publications and landscape reconstruction illustration

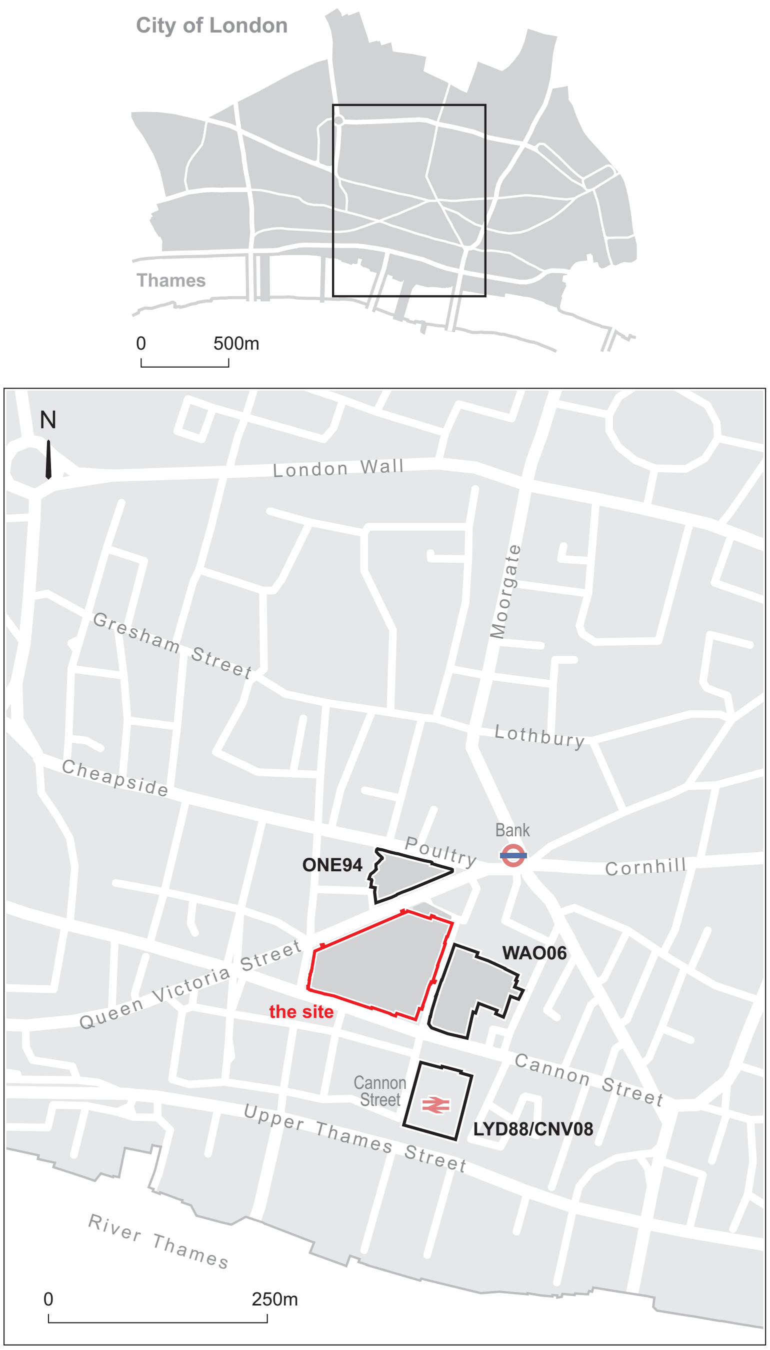


Figure 13.1: Bloomberg London (BZY10) site location with surrounding sites marked (ONE94, WAO06 and LYD88/CNV08) and Roman city map

13.1. Introduction

Bloomberg, London, in the heavily urbanised core of the City, became famous in the 1950s through the discovery of the 3rd century AD temple of Mithras (Grimes 1968; Wilmott 1991; Shepherd 1998). Development between 2010 and 2014 involved the most extensive and significant archaeological excavation of Roman remains in the modern city for 20 years and yielded finds of international significance (Marshall and Wardle in prep; Tomlin 2016). Part of this developer-funded archaeological work involved the construction of a geoarchaeological deposit model, which aimed to use existing and new sedimentary data from the site to visualise the evolution of the past landscape. This was achieved by:

- Reconstructing the underlying prehistoric terrain, which would have formed the landscape template for construction of the Roman city;
- Identifying the likely course of the Walbrook stream, which although now a largely subterranean feature, would at the time of Roman occupation have formed a major north bank tributary of the Thames;

Figure 13.2: View of excavation in progress at Bloomberg London in 2012 looking north with 1 Poultry to the left and St Stephen Walbrook to the right of the site

- Characterising and interpreting the deposits to allow elucidation of the litho- and chronostratigraphic sequences.

The geoarchaeology team was involved early on in the project from the evaluation stage. Test pits and borehole surveys were carried out for archaeological, geotechnical and geoarchaeological purposes (using machine excavators for the test pits and a variety of drilling rigs, a power auger and a hand-held percussion hammer [HHPH] for drilling boreholes). An initial deposit model was produced in 2011. At the start of excavation in late 2011–2012, 170 boreholes were drilled by power auger and recorded by the geoarchaeological team around the site perimeter in order to clear archaeological obstructions for sheet piling. Geotechnical information was gathered later from further boreholes drilled in the southern part of the site and from trench sections; these data points and associated descriptions were added to the constructed model and used during the post-excavation assessment stage of the project. In advance of the forthcoming monograph publication, the model has been revisited and information derived from sites in the surrounding areas has been incorporated in order to contextualise more widely the recorded archaeology.

The model made an important contribution to the project in providing a view of the pre-Roman landscape, interpretation of the prehistoric deposits and inferring the story of Holocene valley evolution, which provided the template for Roman occupation. Key archaeological information from the surrounding area was obtained from a number of sites, including No 1 Poultry (site code ONE94; Hill and Rowsome 2011), the Walbrook Building (site code WAO06; MoLAS 2010a) and Cannon Place (site codes LYD88, CNV08; MoLAS 2010b; Figures 13.1 and 13.2).

13.2. Methodology

Modelling was undertaken using a combination of borehole logging software (Rockworks 15) and a geographic information system (ArcGIS 10.1). Geological and archaeological data for the area held by MOLA included information on sedimentary deposits derived from developer-funded boreholes drilled for geotechnical and geoarchaeological purposes, together with records

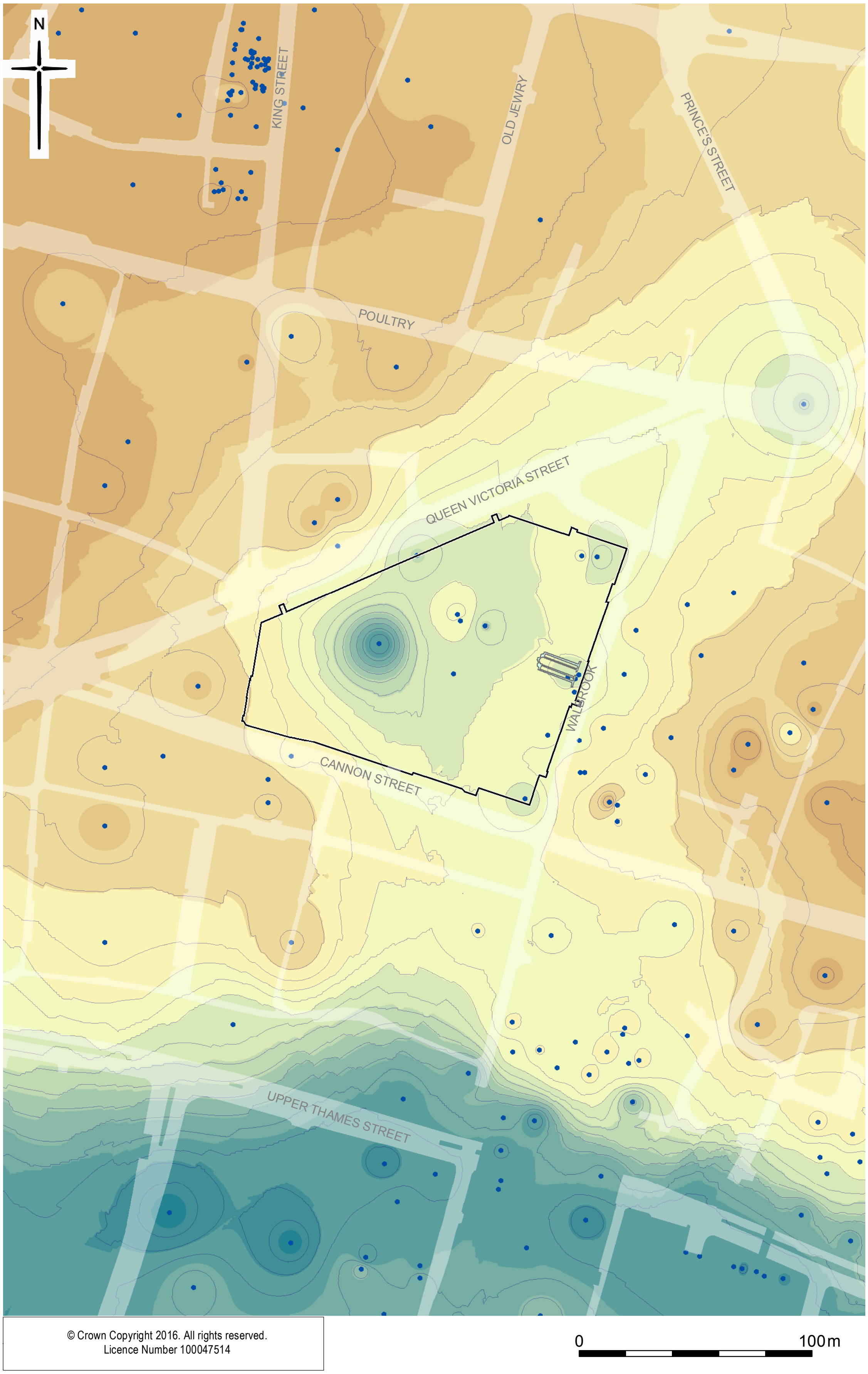
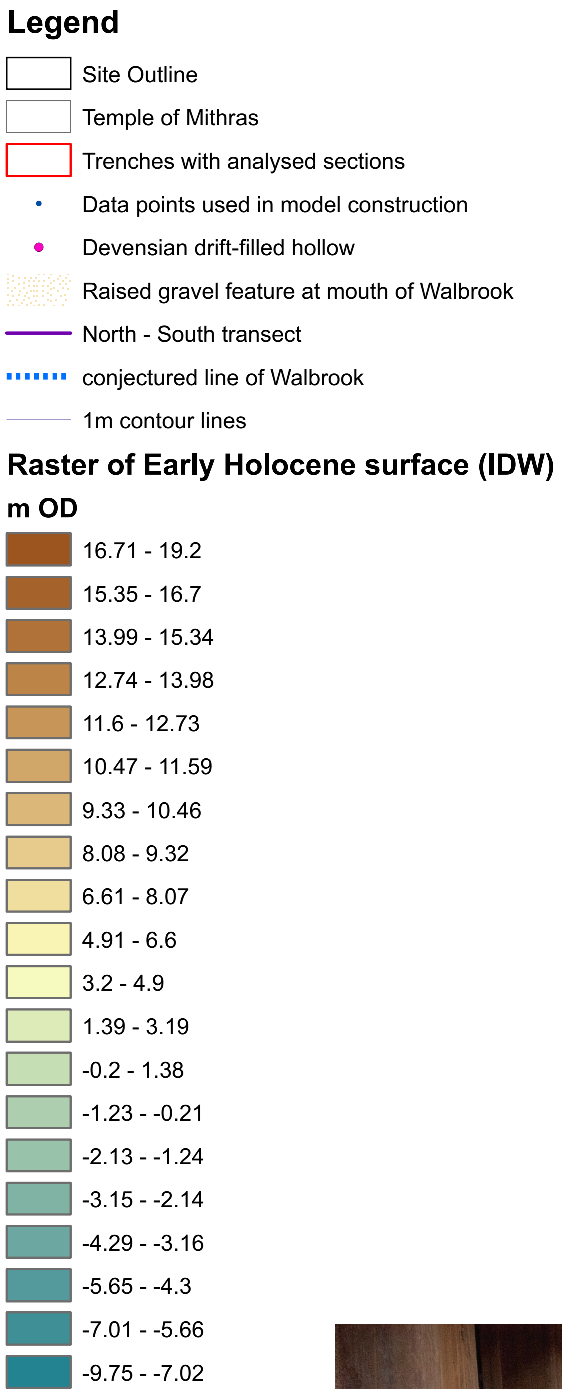


Figure 13.3: Initial deposit model undertaken in early 2011 following site work under site code BBU05 (and in advance of 2011–12 borehole drilling programme). The model is based on an average of 132 points in a c 200m radius from the centre of the site



Key to Figures 13.3, 13.5 and 13.6

held by the British Geological Survey (BGS) and sediment descriptions captured through archaeological interventions. Borehole and archaeological data for the development site and adjacent areas was reviewed and interrogated, allowing construction of a preliminary (basic) stratigraphic model depicting a series of 'working transects'. Reviewed and interpreted data informing the construction of this preliminary model was tabulated, and included information on individual borehole locations (coordinates and elevation data in metres relative to Ordnance Datum), lithological (sediment) descriptions, stratigraphy and mode of origin.

The stratigraphic information included the identification of a key marker horizon denoting the 'Early Holocene surface' (EHS) and reflecting the interface between archaeological deposits and Quaternary drift (terrace gravel or brickearth) or London Clay bedrock. Identifying this horizon allowed the modern ground and archaeological deposits to be stripped away to reveal the contours and topography of the prehistoric landscape, providing thereby a baseline from which to model depositional patterns and provide insights into landscape evolution and urban development. Above the EHS, two stratigraphic units were identified in the early stages of modelling, namely Walbrook channel deposits and other fluvial deposits. The overlying archaeological deposits were treated as a single unit due to their complexity.

Deposit modelling was achieved by combining Rockworks tables within the project GIS. The Spatial Analyst tool was used to build contoured surfaces from the point data of the EHS by means of the Inverse Distance Weighting (IDW) method. Raster images of the contoured surface that represents the prehistoric landscape were produced, and can be represented in 2-dimensions or pseudo-3-dimensions.

13.3. Interpretation

The model developed from the early stages of the project was used by the archaeological and geoarchaeological

Figure 13.4: Drilling auger holes at the northern perimeter of the site during early phases of excavation 2011–12

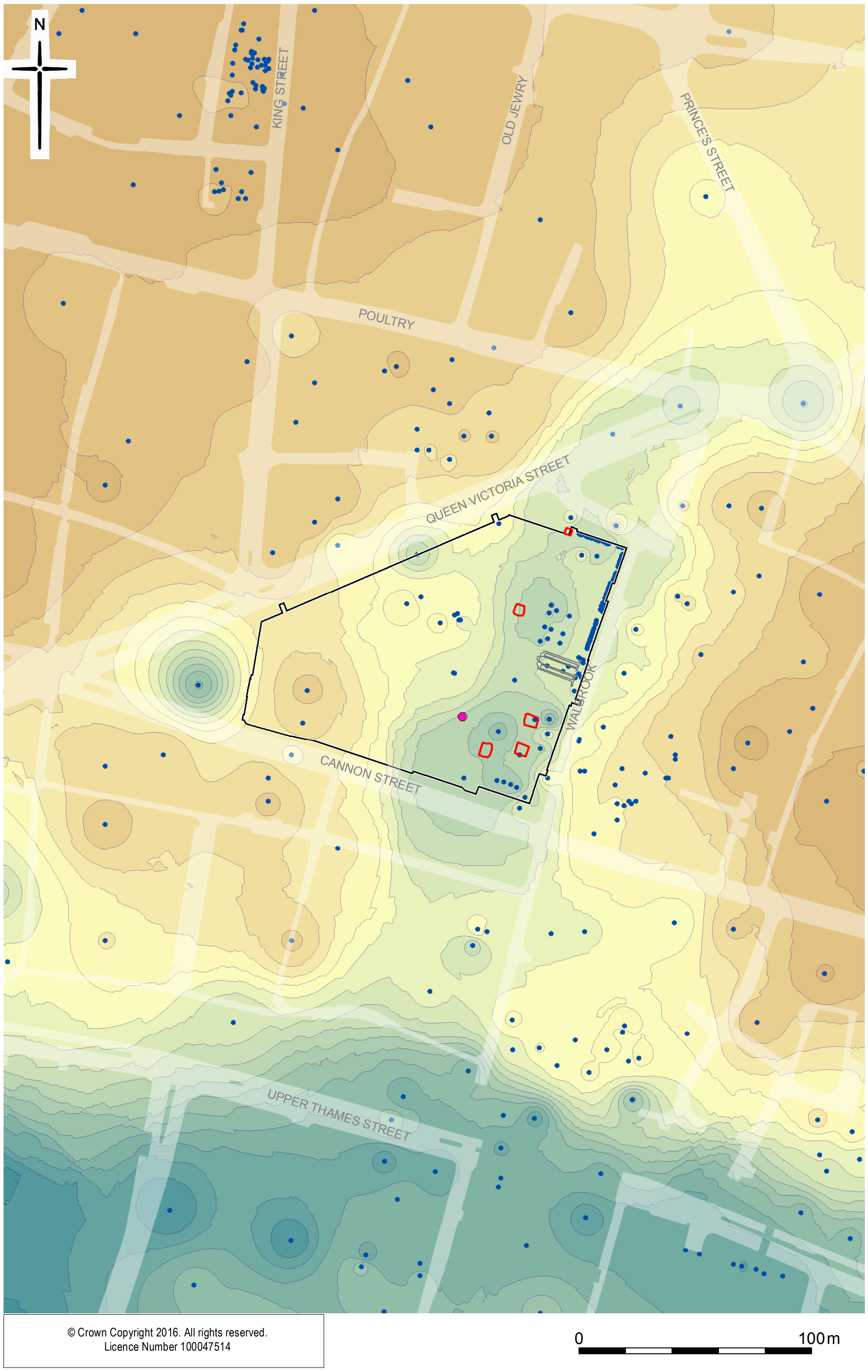


Figure 13.5: Deposit model 2013 including information gathered for the post-excavation assessment report. This model is based on an average of 301 points in a c 200m radius from the centre of the site

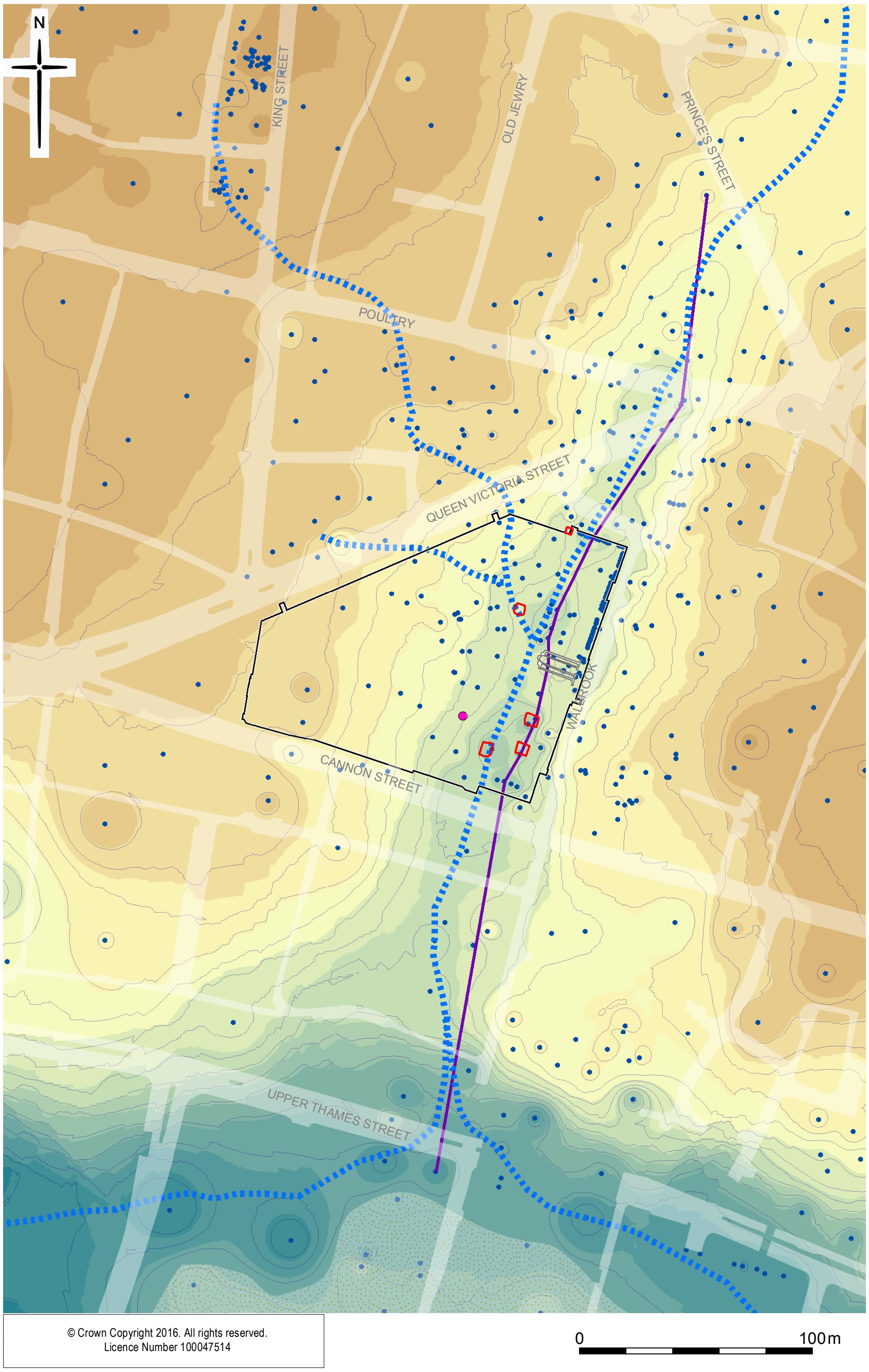
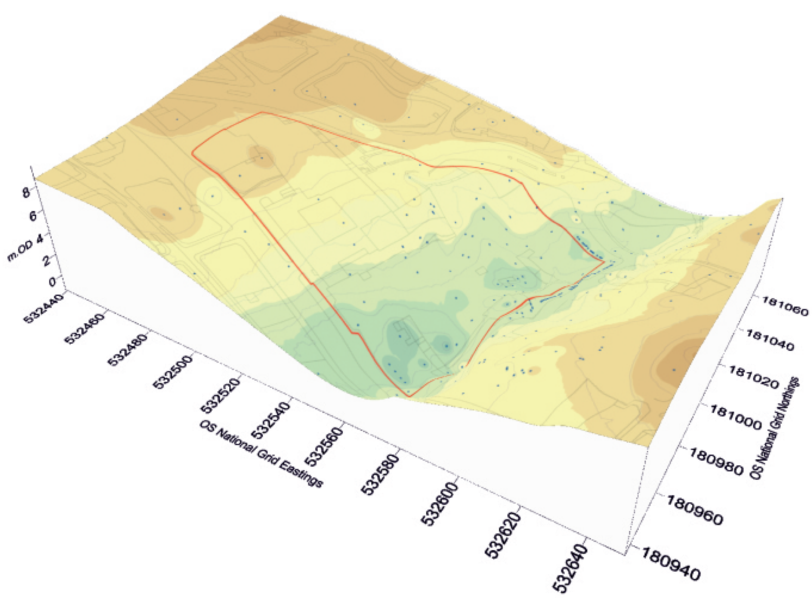


Figure 13.6a: Deposit model 2015 updated for forthcoming monograph publication including contour data derived from excavations at ONE94. This model is based on an average of 452 points in a c 200m radius from the centre of the site;
Figure 13.6b: pseudo-3D representation (Surfer 13) of the 2015 model



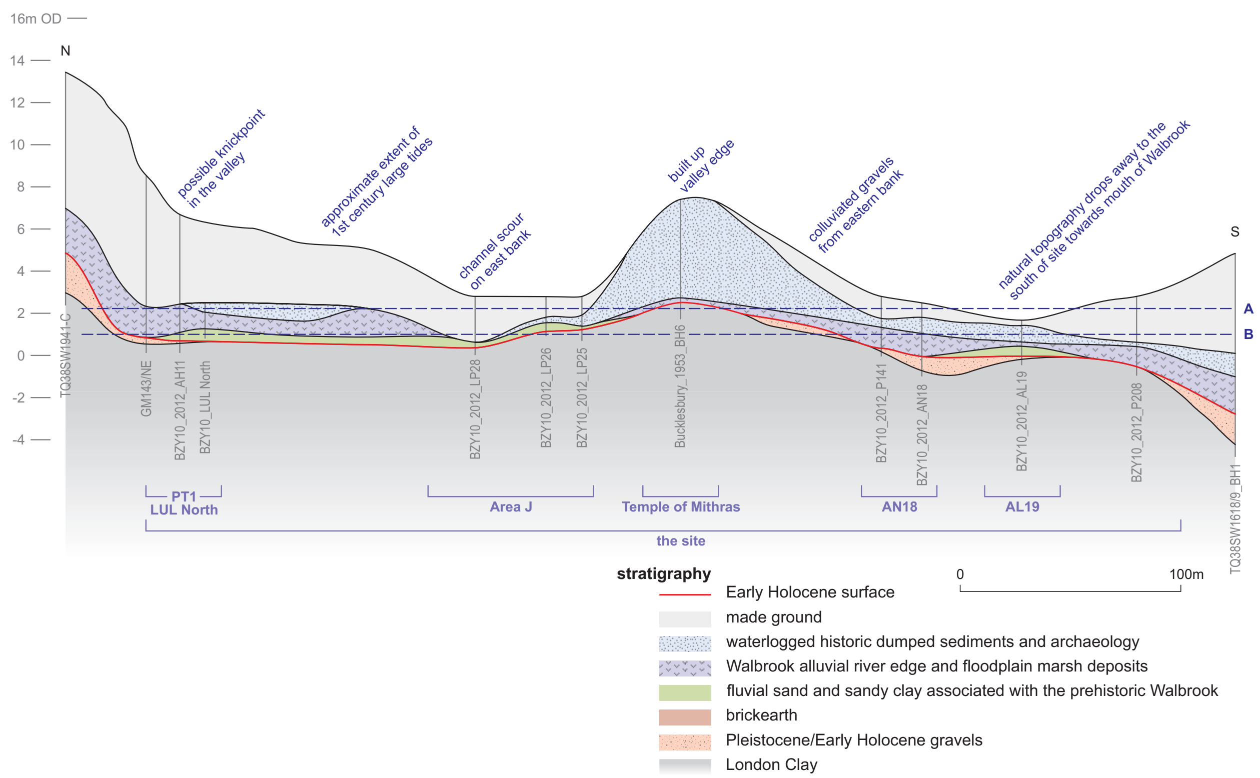


Figure 13.7: North–south cross section intended for forthcoming monograph publication

teams, mainly in the post-excavation phase. Three versions of the model as it evolved are presented here. The first was produced prior to the large borehole drilling campaign of 2011–12 (Figure 13.3). The EHS surface was re-modelled for the post-excavation assessment report, with the inclusion of the results of HHPH boreholes (Figure 13.4), and a selection of on-site profiles was described and sampled by geoarchaeologists during excavation (Figure 13.5). Following environmental assessment, where a handful of profiles was analysed for microfossil content (pollen, diatoms and ostracods) and sediment properties were investigated (soil micromorphology, phosphate analysis, loss on ignition and magnetic susceptibility), the model was refined as a product for publication (Tomlin 2016; Bryan *et al* in prep) (Figures 13.6a, 13.6b and Figure 13.7).

The model was useful as an interactive tool: at each stage of the excavation process the modelled results had an influence on archaeological interpretations, and in post-excavation acted as a guide for sample selection for palaeoenvironmental investigation.

In broad terms, the contour plot shows how the prehistoric topography strongly influenced important aspects of landscape development and urbanisation: for example, through the character of the underlying substrate and its influence on ecology and land-use. Whilst it could be argued that the general shape of the prehistoric valley floor was well known before this study and the application of deposit modelling, the ability through this process to build models that can be revised, updated and viewed from multiple angles and as discrete stratigraphic layers is clearly advantageous from a research perspective.

13.4. Conclusions

Model achievements and outcomes

The model achieved its aims of producing a detailed palaeogeography of the lower Walbrook as a working tool for archaeologists to view the historic landscape and underpin cultural and environmental interpretations. The concept of using the EHS as a key stratigraphic marker is not, however, without its problems; natural erosion and historic quarrying (for example, of brickearth) play an unquantifiable but perhaps significant role in shaping the palaeotopography and character of this surface.

The model aimed originally to identify the course of the Walbrook stream, but, as the scale and rapidity of Roman landscape change became clear, it was realised that the natural prehistoric stream and its urbanised Roman successor should be considered separately. The valley was cleared of vegetation and infilled by the 1st century AD, with the remnants of prehistoric sediment largely lost through erosion and evacuation through the river system. Roman canalisation created an entirely artificial watercourse that bore no relationship to the deepest (and lowest) part of the valley system. Inevitably then, the pre-Roman topography did not influence the line of the Roman stream and for this period any model of the landscape would be informed by the archaeology rather than *vice versa*.

This anthropogenic influence caused the model to focus upon the single (early Holocene) surface and pre-Roman timeframe. However, even the position of the pre-urban stream channel was not apparent during excavation of the deepest parts of the valley and it appears that after the valley shape was initially established (presumably during the Devensian Lateglacial), the stream migrated west across the floodplain. It remains unclear whether the evidence for the immediately pre-Roman stream, which would have formed a sluggish tidal creek, was removed in the deepest parts of the valley by sediment erosion associated with prehistoric deforestation or whether it lay to the west of the excavation area.

Model data, benefits and limitations

The data upon which the model is based is held in Rockworks in a series of related tables, and is backed up as Excel spreadsheets. The benefits of using tables and GIS include the capacity for model revision, growth and replication and the ease of creating contoured plots. The dataset forms part of a London-wide deposit model and is constantly in use within MOLA, assisting desk-based and field staff working on sites across the capital.

In general, sediment erosion and historic truncation have an impact on the reliability of models, but these issues can be overcome if they are taken into account when interpreting the primary datasets used to construct a model and its illustrative outputs. Also important to the accuracy and fidelity of a model is the number (density) and, crucially, distribution of points. Although the limitations of constructing models appear substantial, they are outweighed by the benefits both in terms of a model's predictive capacity and its contribution to understanding the landscape and interpreting the archaeological record.

The modelling at Bloomberg provided an overview of the prehistoric landscape, while the interactive approach led to a significant improvement in the mapping of the subsurface stratigraphy, Despite this, integrating the results of borehole drilling with archaeological knowledge on anything but a coarse scale presented an undertaking that could not be justified within the limits of the project. The use of stratigraphic knowledge remained largely dormant therefore at the assessment level, with the EHS being the operative marker horizon used to influence strategy. In addition, logistical challenges arose from the deployment of a large and diverse team over a lengthy time period. The fieldwork, assessment, analysis and modelling were carried out by different people and, had it been possible, would have profited from coordination by a single staff member.

Acknowledgements

MOLA geoarchaeology gratefully acknowledges the support of Bloomberg LP and their on-site team (archaeologists, engineers, architects, developer and construction team) including Stanhope PLC, Sir Robert McAlpine, Foster & Partners, AKTII and McGee. Additional thanks go to Kathryn Stubbs, Assistant Director Historic Environment at the City of London, Sylvia Warman, Historic England Science Advisor for London and Jackie Skipper (Geological Consulting Group).

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Constructing a geoarchaeological deposit model: Bloomberg

↓

Assess pre-existing data

- Sections from 1950's excavation reports (original archaeological excavation of the site)
- Other geoarchaeological and archaeological fieldwork records (boreholes and sections) from site and surroundings
- Published information about pre-Roman Walbrook topography and drainage
- Geotechnical records from British Geological Survey and client

↓

Develop rationale for model construction and key aims and objectives

- Reconstruct immediately pre-Roman topography
- Identify likely course of the pre-Roman and Roman Walbrook stream

↓

Commission further ground investigations, including:

- Model not done for predictive purposes. Instead, it was constructed during and after phased excavation that examined all surviving deposits on the site. The model was progressively updated to make use of this information during the fieldwork and post-excavation stages.

↓

Can the deposit model be constructed using pre-existing data?

Yes, but its reliability increases as each phase of new data is added.

↓

Construct deposit model comprising of:

- Working transects drawn through all available data-points
- Key marker horizon (Early Holocene Surface) – approximating to pre-Roman topography
- Distribution of Walbrook channel deposits;
- Distribution of archaeological deposits.

↓

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- Deposit model used to select environmental samples for assessment during post-excavation stage
- Close working with archaeological stratigraphic team to interpret results.

↓

Revise final product

Clear limitations of the modelling for mapping the canalised Roman Walbrook, but updated model useful for publication illustration of immediately pre-Roman river and topography.

↓

Archive and reuse

Rockworks tables and Excel spreadsheets held by MOLA and form part of a London-wide deposit model that is constantly in use and regularly updated by MOLA geoarchaeology team.

14. Deposit modelling of a Roman and later urban landscape: St Mildred's Tannery, Canterbury, Kent

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Canterbury Archaeological Trust (CAT), 92A Broad St, Canterbury, CT1 2LU

Abstract

Development of a heavily contaminated, brownfield site straddling the river Great Stour in Canterbury provided an opportunity to reconstruct the Roman and later urban landscape using deposit modelling, aided by reference to previous archaeological investigations. The deposit model was constructed using bespoke software designed by the author, which helps produce 2-dimensional or 3-dimensional representations of site stratigraphy, simplified synoptic views and/or fence diagrams. Since 2004 the approach used at this site has been adopted by CAT for other archaeological interventions in Canterbury and its environs. This methodology helps to design better-targeted and more cost-effective evaluations, determining beforehand where external specialists can best be deployed, and enables the examination of archaeological and geoarchaeological deposits beyond and below the usual limits of excavation.

14.1. Introduction

Developer-funded work by Canterbury Archaeological Trust (CAT) ahead of residential redevelopment on 3.5ha of land at and adjoining St Mildred's Tannery, Canterbury (Figure 14.1), commenced with a desk-based assessment in 1999–2000. This was followed by preliminary trial-trenching in 2001 and watching briefs on geotechnical site investigations in 2001 and 2002 (Pratt and Sweetinburgh 2004).

The site straddled a branch of the river Great Stour and was mostly situated within the modern floodplain; this comprised fine-grained alluvium underlain by late Pleistocene sands and gravels. However, there were higher areas within the site, underlain by 1st terrace sands and gravels sealed by brickearth. Pre-existing archaeological evidence indicated that the site was crossed by significant Roman features including the London-Dover road (Watling Street), by an existing street with a Roman predecessor and by the line of the Roman and later defences. Roman buildings, partially overlain and surrounded by peats, had also been found in two trenches during previous investigations (Blockley 1987; Pratt 1992). Following the Roman period, a charter of AD 804 (Sawyer 1968, S160) granted the Abbess of Lyminge a 'refuge' here and rentals record mixed usage, including the presence of a mill by the late 12th century (Urry 1967); much of the site was later farmed by Franciscans. In the mid-19th century, industrial-scale tanning took place on the site, leaving up to four metres of contaminated waste over much of the area. This scale of contamination had a significant influence on construction design and groundwork methodologies, which in turn impacted on the nature and scale of archaeological interventions. Furthermore, when construction began in 2004, a strategy was adopted of preservation of archaeology *in situ* where possible; attempts were made, therefore, to limit excavation and the recording of stratigraphy to service trenches and other infrastructure interventions, although where groundworks extended beyond these features additional recording was undertaken by watching briefs.

Given the lack of large-scale surface excavation across the site (Figure 14.2), the most effective approach to investigating and reconstructing the spatially extensive archaeological record was to use deposit modelling to explore how geology, palaeotopography, and floodplain development influenced the location and nature of human activity during Roman and later occupation (Pratt 2009).

Comparative data table of this deposit model	
Deposit model location	Canterbury, UK (NGR: 614500 157700)
Depositional environment	Floodplain of the river Great Stour, adjoining 1st Terrace sands and gravels and overlying brickearths
Size of deposit model	Site *c* 3.5Ha
Data collection strategies	Review of pre-existing site investigation (SI) logs, watching briefs (WBs) on SI boreholes, test-pitting and other groundworks (including piling), purposive mechanized augering , evaluation trenching and limited excavation
Position in the archaeological process	SI data review included in desk-based assessment but not formally modelled. Deposit model developed in tandem with archaeological fieldwork, which involved evaluation between two pre-application SI WBs, with phase plans produced. WBs on later SI's, along with augering prior to each piling campaign, in parallel with various other WBs and limited excavations
Reason for deposit model construction	To test and develop conjectural reconstructions of Roman and later topography based on limited excavation
Archaeological question	What influence may palaeotopography, geology and floodplain development have had upon Roman and later human activity and occupation?
Software modelling process	Data importable from several formats but usually input using custom-built (in dBase) software. This constructs formatted logs and CorelDraw script for draft pseudo-sections along transect lines. To these, stratigraphic sections, interpretative groups, phases and other information are added manually. Group numbers and phasing is passed back to the database and added to formatted logs. CorelDraw script generated to draft stratigraphic group matrix. Data and blanking files generated for Surfer are used to check for anomalies that may represent data error, algorithmic artefacts, misinterpretation of data or overlooked features. Such problems are addressed and individual group descriptions are added to the database; this regenerates formatted logs and collates group descriptions with other information. The main report text is written and all other outputs finalized
Outputs from the deposit model	Datasets suitable for other systems. Formatted text logs and structured group text. Phased stratigraphic group matrix. Detailed pseudo-sections projected onto nominal transect lines, usually with an exaggerated vertical scale, and simpler synoptic sets of these, usually with less or no distortion. Fence diagrams can be constructed manually using the latter, but data density is usually too great for this to be useful. Borehole and test pit pseudo-sections scaled as overlays for conventional section drawings. Distribution and contour maps (sometimes overlain) and 3-dimensional surfaces of selected contexts, groups or phases: contours and 3-dimensions can show Ordnance Datum or Below Ground Level values for the top or bottom or overall thickness of the selected unit(s)

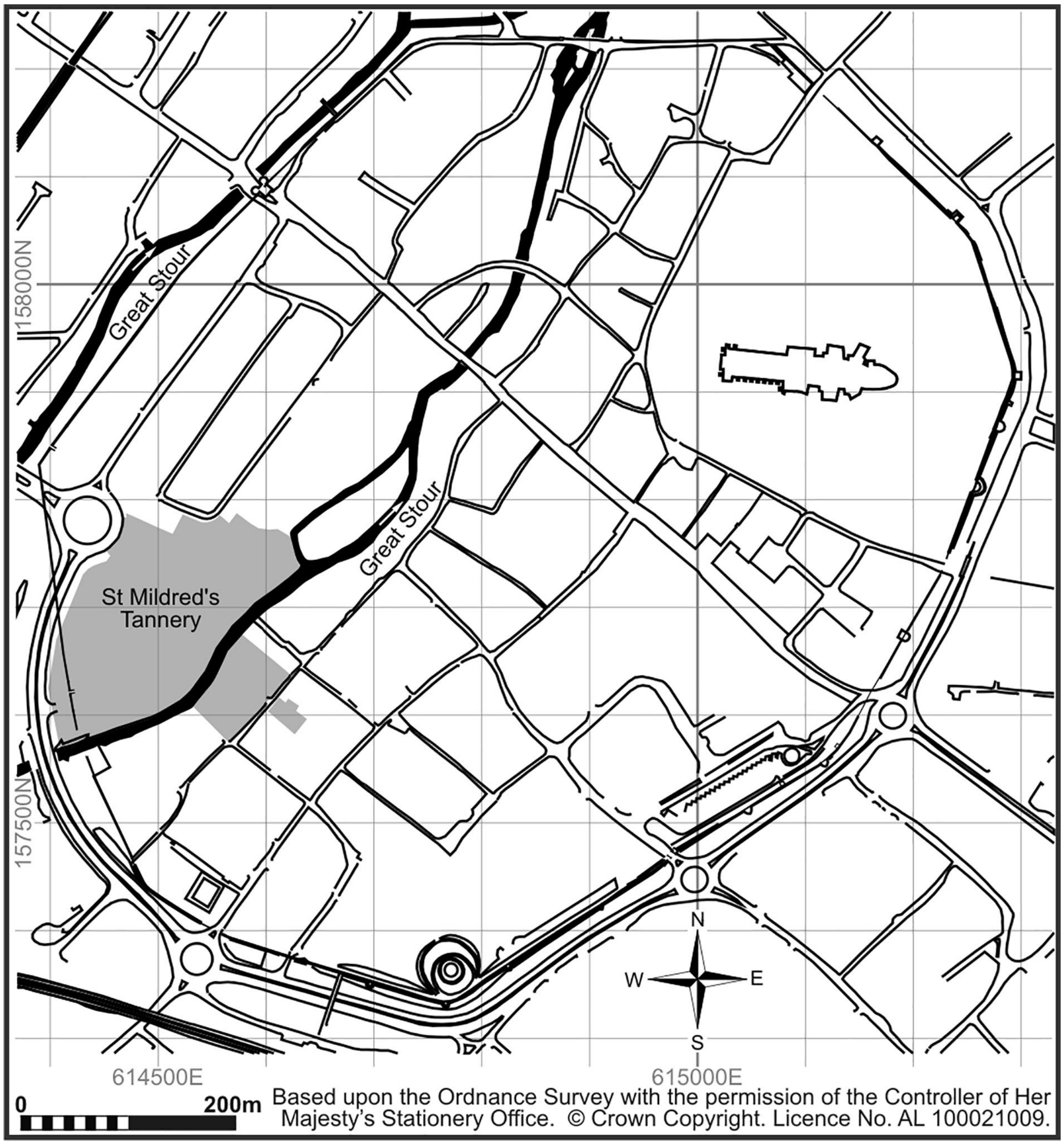

Figure 14.1: Site location in relation to the walled city and river

14.2. Data Collection

Data for deposit modelling were captured from sediment descriptions collected during geotechnical or archaeological augering, watching briefs and limited excavations (Figure 14.3). Piling plans were compared to existing archaeological data and conjectural site stratigraphy, and some of the positions were selected for investigation by windowless sampling. Most positions were chosen to create transect lines or to enhance existing transects. The resulting 1m long core liners or, in some cases, loose samples were bagged and labelled. Samples retained within plastic tubes were opened and the sediments were described and photographed; representative material was sub-sampled for further analysis (Figure 14.4).

To facilitate deposit modelling, bespoke software was written by the author in dBase. Drilling logs and other sediment descriptions collected during excavations and watching briefs were transcribed into a main (context) .dbf file. Coordinates, ground levels and dating evidence were added and the data were used to draft formatted text logs for each position. These logs were reviewed and each context was assigned a colour code representing a general sediment/cultural horizon type; cross-sections were then reconstructed along transect lines (Figure 14.5). Re-scaled trench sections were added manually to the transects to enhance the understanding of site stratigraphy. Each context was assigned to a general lithological group, but for transparency and to facilitate potential re-analysis, field interpretations were retained in the detailed logs. Group numbers were added to the database and each

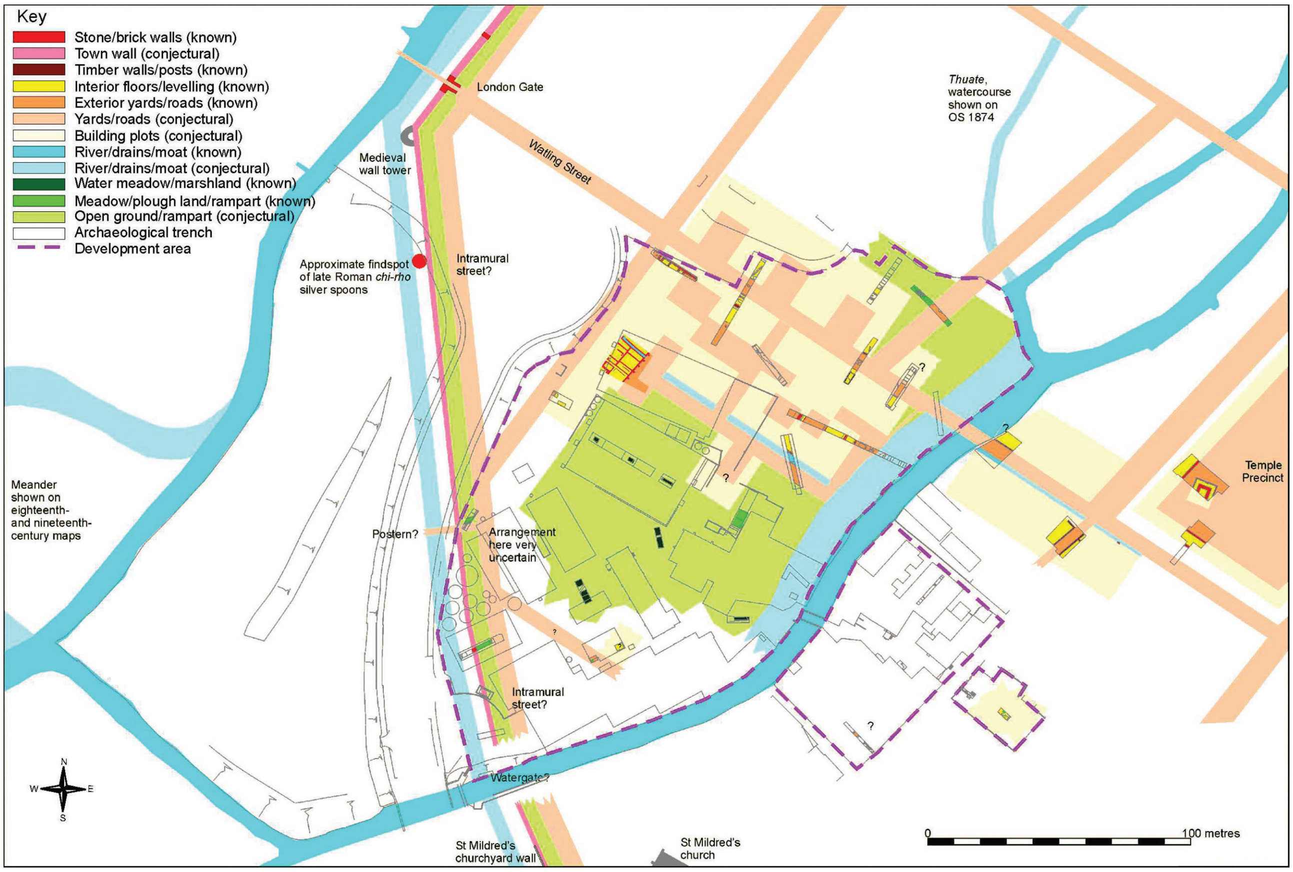

Figure 14.2: Roman reconstruction prior to deposit modelling

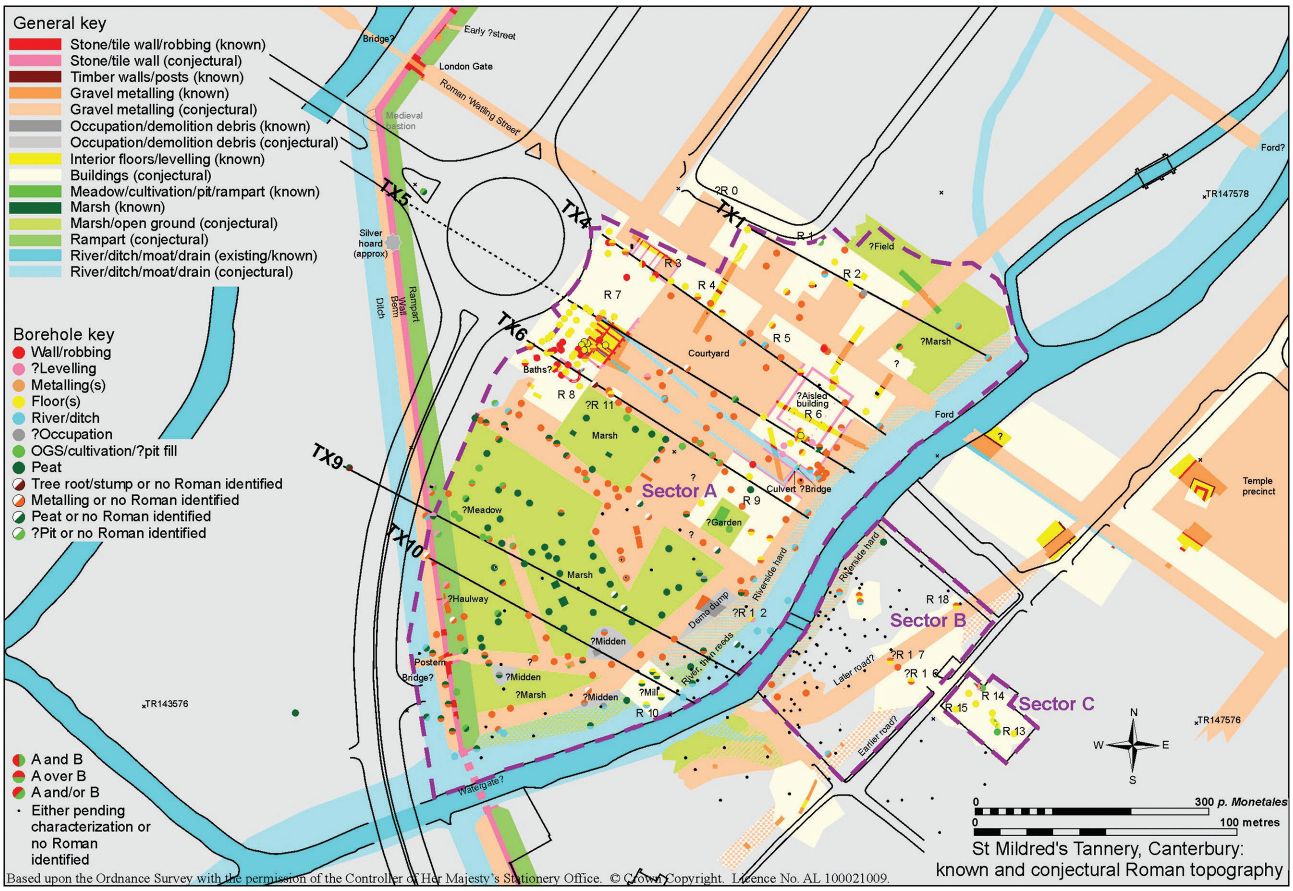

Figure 14.3: Roman reconstruction following deposit modelling. Note how R6 has altered, R9 migrated south and the putative intramural street lost. TX lines indicate transects shown in Figure 14.6

Figure 14.4: Logging table and a detail of its trough, holding a windowless-sample of a Roman wall

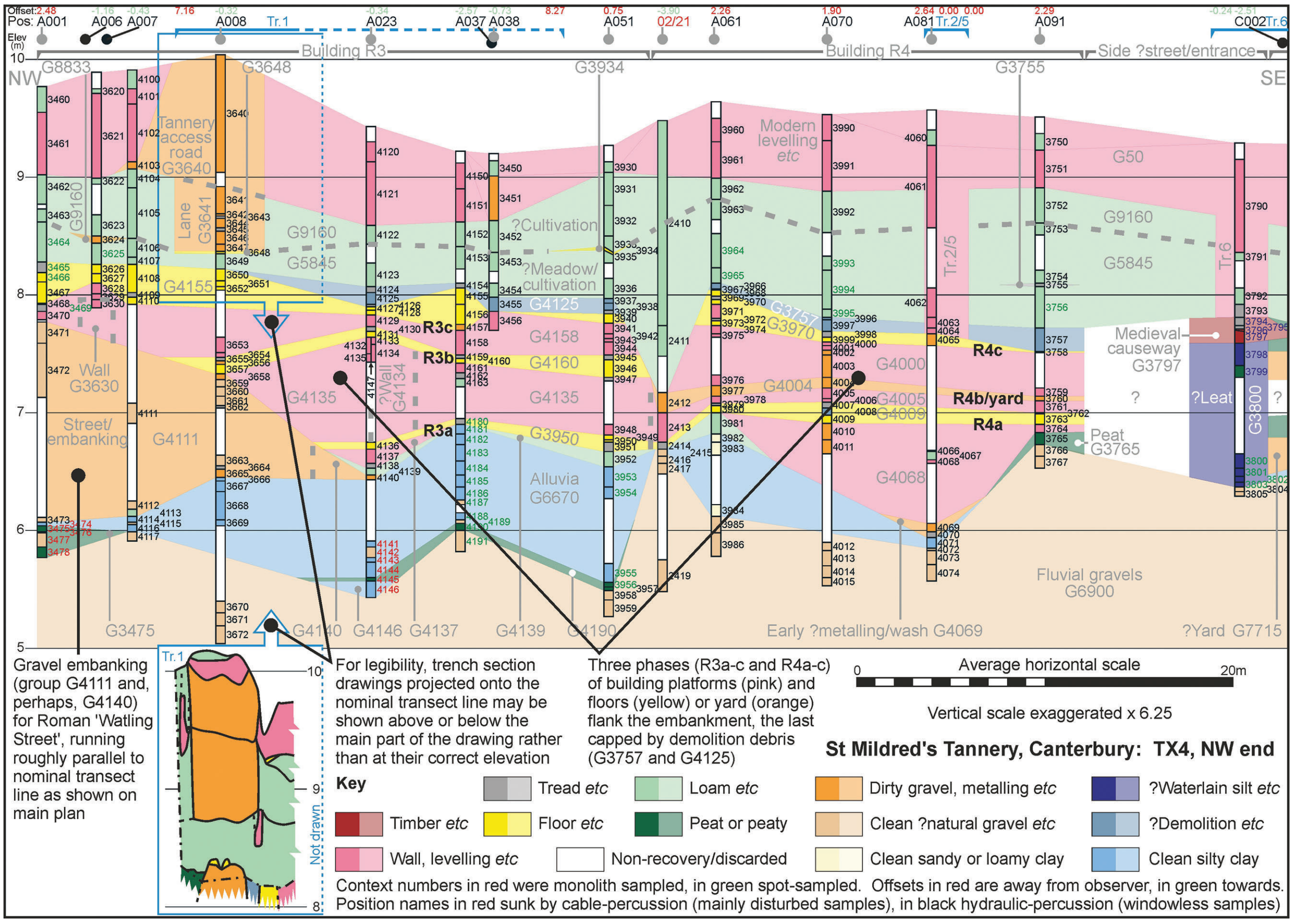

Figure 14.5: North-west end of transect TX4: although this level of detail may be unnecessary for the final report, it is all of use during analysis

group was phased. Phase and site summaries were written for the main report text, with logs and group descriptions appended. Multiple cross-sections were combined to produce simplified synoptic views and/or fence diagrams (Figure 14.6). The software was also used to export files for Surfer to produce 2-dimensional or 3-dimensional representations of the top, bottom, thickness or 'below ground level' depth of selected contexts, groups or phases (Figure 14.7).

14.3. Interpretation

Modelling of the site indicated that the pre-Roman ground level was probably around the height of the contemporary floodplain water-table, allowing shallow peats to form in some places. By dovetailing the results of deposit modelling with evidence from earlier excavations and desk-based assessments, it was possible to reconstruct the Roman and later topography of this part of the city (Figure 14.3). This work also highlighted the challenges of living within the floodplain, some of which are described below.

Deposit modelling demonstrated that a gravel embankment carried Watling Street across the valley floor; this feature dipped towards the river suggesting the presence of a ford. Attempts appear to have been made to build up soggy ground on some parts of the floodplain by laying gravel surfaces, some of which subsequently formed the foundations of yards, side-streets and buildings. The high water-table undoubtedly created problems for the inhabitants; for example, previous excavation (Blockley 1987) of building R7 demonstrated three main phases of construction, with each floor set significantly higher than its predecessor to alleviate the impact of a rising water-table. Further evidence for rising water levels was provided by peat layers mapped across the site, which have demonstrable relationships to Roman remains including drains, leats and floor levels.

A cluster of clay and gravel surfaces sealing thick deposits of organic and inorganic silt was identified projecting into the former river channel; these surfaces were tentatively interpreted as evidence for a Roman or Anglo-Saxon mill (R10). This (mill) structure suggests that rising water-tables did not entirely restrict activity on the floodplain. 9th century pins were recovered from a gravel surface above Building R6 on what was interpreted as an island of higher ground that may have been partially cultivated during this period. The surrounding peat deposits appear to have formed in two discrete phases;

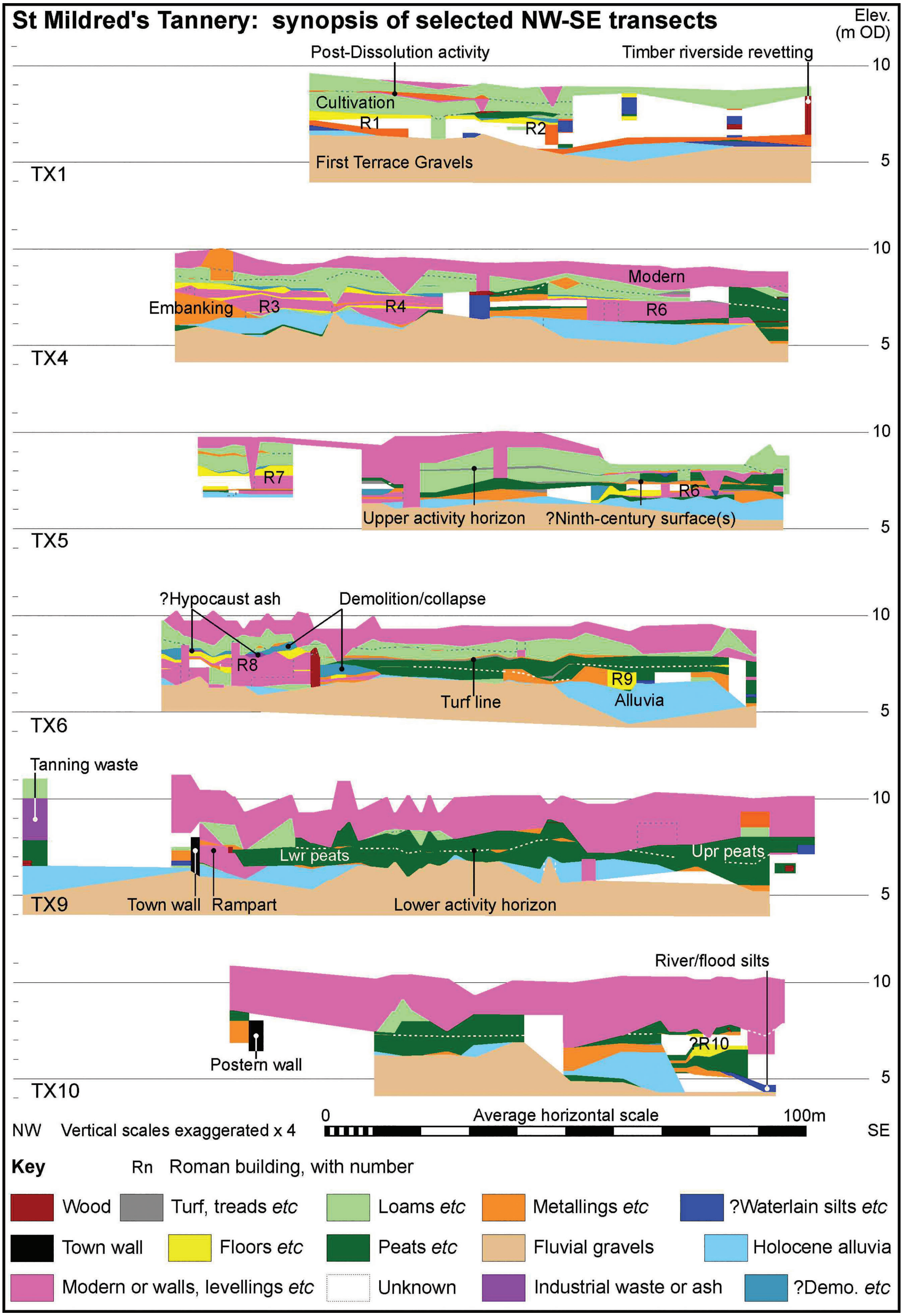

Figure 14.6: Synopsis of selected transects: the horizontal scale is averaged as individual boreholes are represented by an exaggerated width and some are slightly repositioned for legibility in the detailed versions

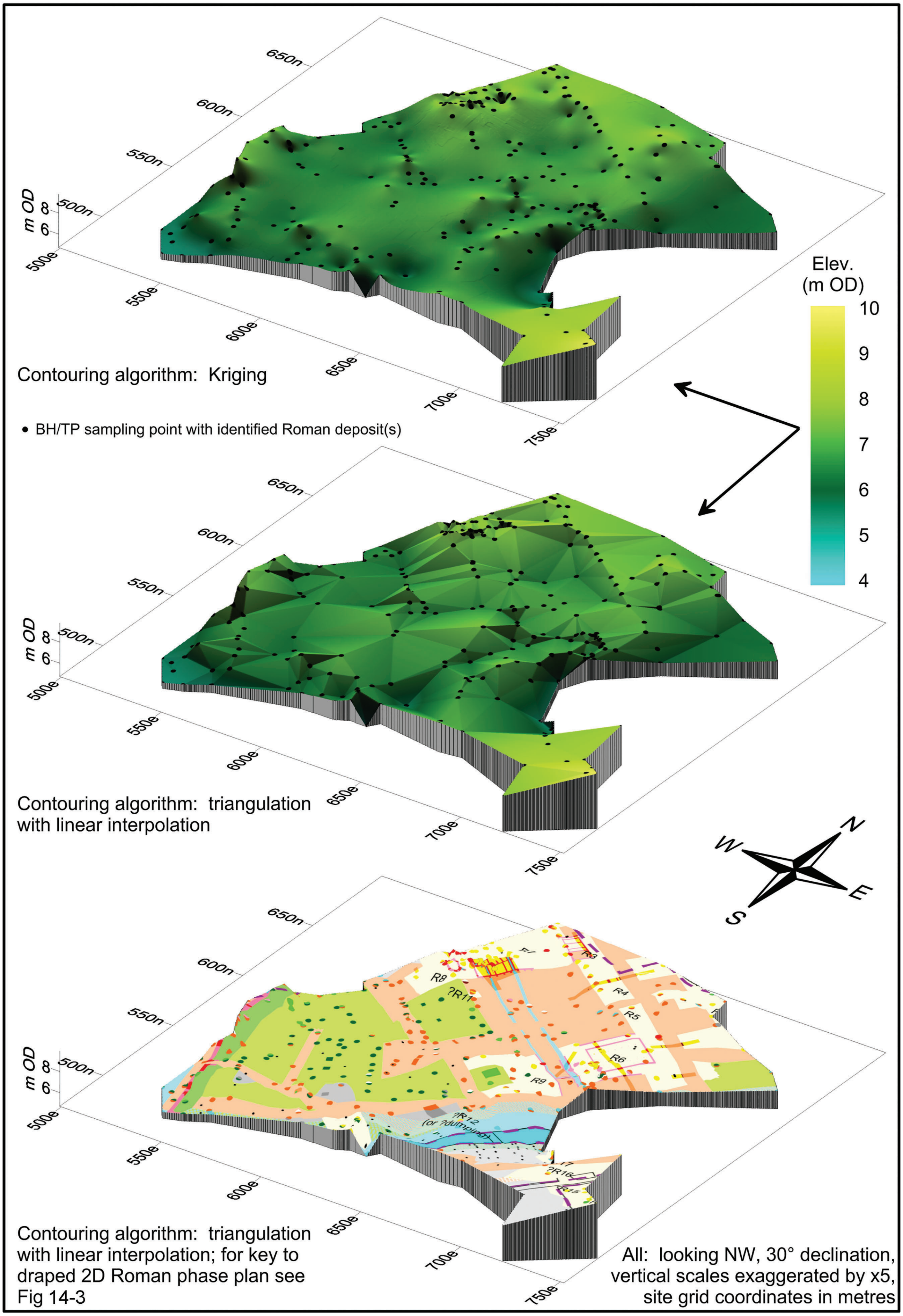

Figure 14.7: 3-dimensional images of the final Roman surface using two contouring algorithms: without expending considerable labour creating break lines or false coordinate triplets, neither will match more detailed 2-dimensional representations very closely

these were separated by an 'activity horizon' marked, variously, by a brushwood trackway, light metalling, trodden surfaces or simply a thin layer with significantly more flint, tile and bone than the surrounding sediments.

14.4. Conclusions

Data collection began with site investigation watching briefs in 2001–2002, but only with the start of purposive augering in 2004 was deposit modelling adopted as a form of preservation by record and as a means to target more effectively future evaluation trenching. It has proved to be a significant analytical tool, enabling CAT to contextualise many otherwise isolated excavations and observations and to produce relatively detailed, albeit conjectural, topographic reconstructions. This approach was cheaper than conventional excavation over such an area with challenging ground conditions, yet it provides curator and researcher alike with enough information to be useful, and enough uncertainty to be interesting. Where it has been tested by subsequent augering or excavation, the model has proved reasonably robust. The purposive augering was based upon relatively tightly spaced linear transects, but in hindsight, more evenly distributed sample locations may have been preferable for some locales. In addition, although post-excavation changes to field interpretations were not separated initially, they now occupy their own field and are differentiated in final logs.

Since adopting this methodological approach, data elucidating depositional environments and associated archaeological activity in Canterbury, especially for the Historic Period, has accumulated rapidly. Detailed 2-dimensional and 3-dimensional geoarchaeological models similar to the one described here have been produced for small areas of Canterbury and beyond, and are being used increasingly to inform mitigation strategies and the use of other techniques: for example, targeted optically-stimulated luminescence dating. These deposit models and their source data, including the one described here, form part of the permanent site archives and are available digitally for reinterpretation or inclusion in wider models of Canterbury and its environs.

Acknowledgements

Archaeological investigations at St Mildred's Tannery were overseen by a steering committee representing CAT, Historic England, Canterbury City Council, Bellway Homes (principal developers), their design and engineering consultants, and by Martin Biddle and Birthe Kjølbye-Biddle (archaeological consultants). Bellway Homes are thanked for providing funding for the vast majority of this work.

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SECTION 7

Modelling as an aid to sustainable resource management

15. Characterising the waterlogged deposits beneath Nantwich, Cheshire: the application of deposit models beyond simple stratigraphic analysis

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Abstract

This paper describes the approach taken to investigate the urban waterlogged deposits in Nantwich, Cheshire, in order to establish a baseline and management strategy for continuing preservation of organic remains (Phase 1), funded by Historic England and Cheshire County Council. In order to characterize the physical and chemical nature of the deposits, and to map their extent, depth and chronology, a programme of borehole drilling was undertaken in 2007 to retrieve cores for detailed description and sub-sampling. The study showed that up to 4m of archaeological deposit had accumulated in parts of the town, and that the onset of widespread waterlogging occurred in the Late Saxon period and continued into the 13th century. Although preservation conditions varied over the 10Ha of 'urban wetland' some exceptionally good preservation was recorded uphill from the River Weaver, contrary to the logic of wet conditions in the floodplain providing the most likely location for waterlogging. The reasons for this are explained below, as well as the techniques and methodology adopted to gather and analyse the data. A subsequent programme of monitoring from 2011–2016 (Phase 2) is reported elsewhere.

15.1. Introduction

Nantwich is an ancient salt-working town located on the River Weaver in central Cheshire (Figure 15.1). The survival of archaeological remains within the town is of similar national importance to those in Berwick-on-Tweed (Derham 2013), Bristol (Wilkinson *et al* 2013), Carlisle (Zant *et al* 2013) and York (Holden *et al* 2009) due to the depth of accumulation and the condition of preservation. Basal geology comprises Mercia Mudstone Formation with glacial till above, which is present across wide areas to the east and west of the River Weaver and forms the main geology beneath Nantwich. The river terrace deposits which overlie the clay consist of sandy silts with clay and gravel, which can extend to 3m–5m in thickness. Above the natural geological strata, anthropomorphic

Figure 15.1: Location map: Nantwich and selected waterlogged sites in England

Comparative data table of this deposit model	
Deposit model location	Nantwich, Cheshire, UK (NGR: 364961 352403)
Depositional environment	Urban build-up across Holocene valley floor and adjacent Pleistocene glacial and river terrace deposits
Size of deposit model	Incorporates data over a *c* 20Ha urban area
Data collection strategies	Review of information collected previously during geotechnical investigations and archaeological interventions. Drilling of 30 purposive boreholes with a windowless percussive rig to characterise the mineralogy and geochemistry of the sediments and to collect samples for dating and palaeoenvironmental analysis. Dipwells were fitted in borehole voids to expedite any future monitoring study
Position in the archaeological process	Part of a funded research study to inform future planning decision-making within the historic urban area
Reason for deposit model construction	To establish the sedimentary character, 3-dimensional urban stratigraphy and hydrological and geochemical pathways through the deposits
Archaeological question	Can a best practice methodology which will inform future management and preservation strategies for the investigation of waterlogged urban deposits be established?
Software and modelling process	Borehole logs were plotted using gINT. Surfer was used to create 3-dimensional surfaces. Stratigraphic sections were constructed by hand and converted to digital format using Adobe Illustrator. GIS was used for spatial analysis
Outputs from the deposit model	A series of images including stratigraphic cross-sections, an isopach map of dissolved oxygen content and zones of preservation were created to aid visualisation. Project metadata was archived with the ADS

deposits have accumulated up to *c* 4m in depth from the current ground surface, comprising organic-rich silts, as well as archaeological horizons with carbonized organic remains, and more recent made-ground. Salt-working and flooding, as well as domestic and stable waste, have contributed to the build-up of deposits, which at times are interspersed with redeposited mineral-rich horizons.

Previous discoveries had revealed deep waterlogged deposits which date from Iron Age times, but the *Nantwich Waterlogged Deposit Study* has identified a significant growth of accumulation during the Late Saxon and medieval periods through a programme of radiocarbon dating (SLR 2009, 65). This richness of material posed a problem to development control as regeneration pressures were high within the historic core of the town. Cheshire County Council's Historic Environment Team (later Cheshire Shared Services) persuaded Historic England (at the time, English Heritage) to fund research into these deposits so that a well-informed management strategy could be formulated.

A project design and specialist team was provided by SLR Consulting with support from York Archaeological Trust and Palaeoecological Research Services. This included an archaeologist (the author), a geological engineer, a hydrogeologist, a GIS technician and illustrator, a conservation scientist and a palaeoenvironmentalist. Although the initial project, completed in 2007, comprised a desk-based assessment of available information, this was followed by field collection of bespoke data and environmental analyses through a programme of coring, sampling and analysis described more fully below (Section 15.3). The project was advised by a Steering Group comprising representatives from Historic England and Cheshire Shared Services (Archaeology).

15.2. Aims and objectives

The specific aim of the project was the development of a best practice methodology for the investigation and characterisation of waterlogged deposits, using Nantwich as a case study. Specific objectives were to: (1) determine the physical and chemical parameters governing the preservation of the organic deposits at Nantwich; (2) map their extent spatially and vertically and establish a chronological framework; and (3) establish how they had formed and how they had continued to be preserved over the centuries.

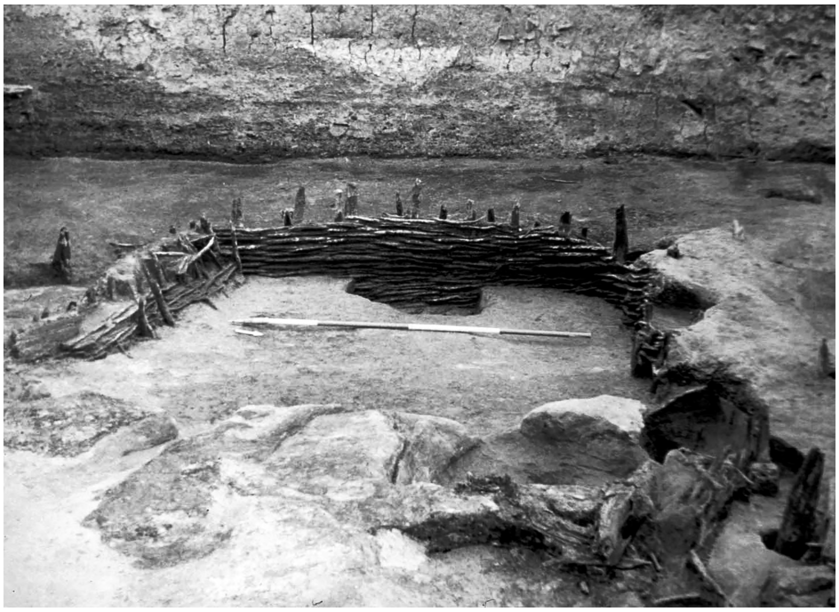


Figure 15.2: Waterlogged deposits and well-preserved organic remains: 2a wattle-walling for a wych house (Robina McNeil excavations 1970s), 2b tub-staves and planking (Tim Malim, Lamb Hotel 2003), 2c salt-barrels and salt-ship under excavation (EAS 2003)

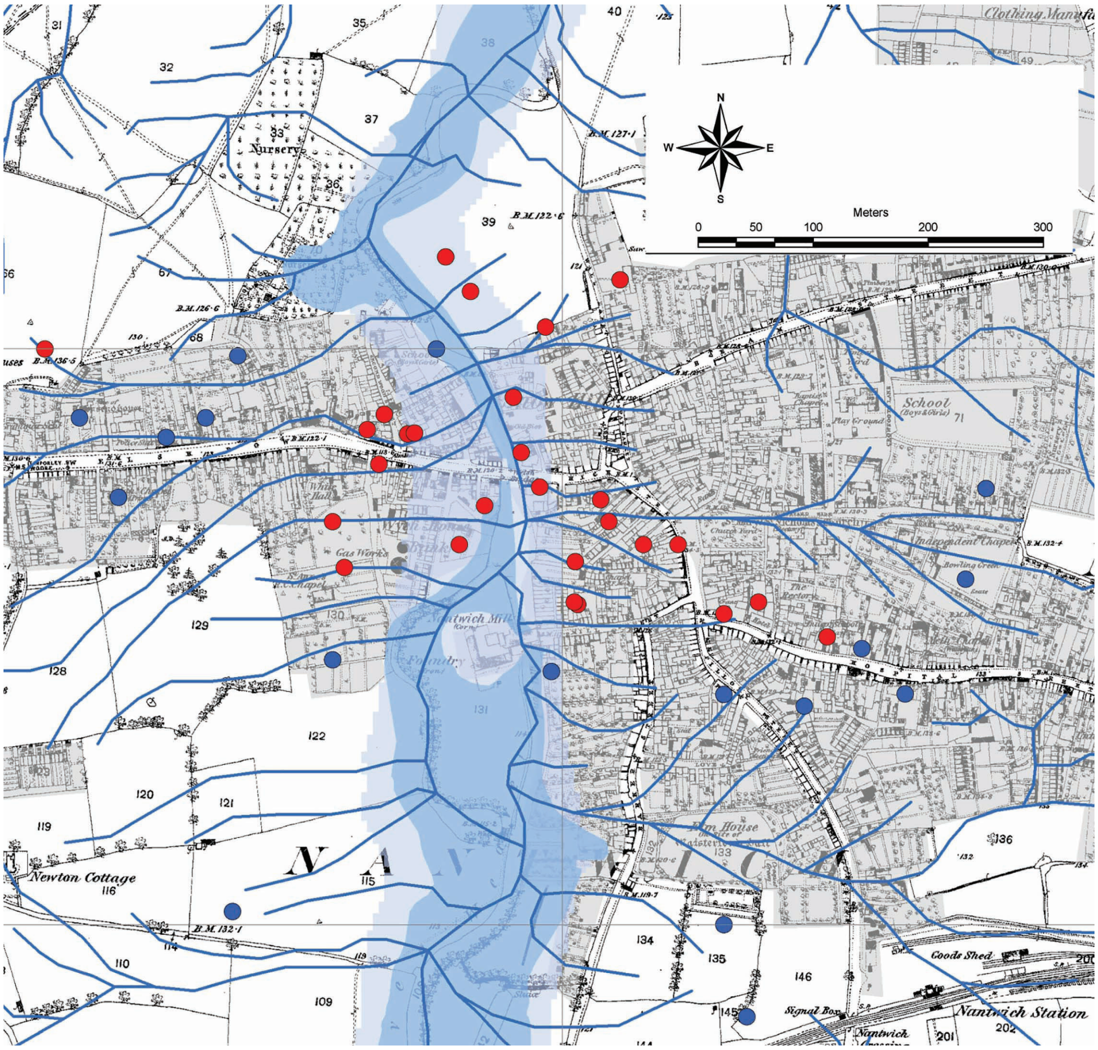


Figure 15.3: Nantwich with 1st edition OS map and natural flow accumulation paths superimposed (red dots waterlogged deposits from previous excavations, blue dots show excavated evidence for no waterlogging)

15.3. Methodology

Prior to the inception of the project, information had derived from watching briefs and excavations during the 1970s and 1980s, and PPG 16 developer-funded investigations thereafter (see for example Earthwork Archaeological Services 2006; Hayes 2005; Hutchings 1985; Le Quesne 1995; McNeil 1983; Reid 2004; SLR 2007 Table 1 and p.15-17) (Figure 15.2a-c), as well as some borehole data (Cheshire County Council Geotechnical Services logs for Snow Hill and Kingsley Fields [see SLR 2007 Table 1 and p.18]). The quality of this information was variable. Few of the over 100 boreholes had geotechnical records surviving for analysis as they had not been retained after permission had been granted for development. Even when boreholes for infrastructure projects such as road schemes were available, these failed to contain much geotechnical data that was sufficiently detailed to aid the desk-based study. Reports from archaeological interventions also often failed to contain heights above Ordnance Datum or even reliable national grid coordinates, further hampering their use.

The initial desk-based study in 2007 incorporated what was of value from these site investigation sources, and supplemented them with bespoke data collection. This latter stage consisted of drilling 30 boreholes across the historic core of the town to retrieve cores for detailed sediment description and sub-sampling for dating and environmental analysis.

Background data included contemporary Ordnance Survey (OS) mapping, historic OS and other older maps that could be georeferenced, geological data, hydrogeological data and hydrological natural flow accumulation paths to help understand the subsurface topography and hydrology (Figure 15.3). Digital terrain models were created using these datasets, thereby allowing information to be reviewed and analysed within a 3-dimensional environment. Baseline conditions were established in 2007 with a programme of geochemical and palaeoenvironmental sampling, using cores extracted by a windowless percussive rig (Figure 15.4). Each core (1m long and 100mm diameter) was recovered in a Perspex sleeve, which was sealed rapidly and stored in cool and light-free conditions before processing. The lithology of each core was described before sub-sampling to identify the degree of preservation of plant macrofossils, pollen, diatoms, insect remains and wood. Material that would be suitable for radiocarbon dating was also identified.

Analysis included permeability testing of the sediments and lithological descriptions; geological descriptions followed British Standard 5930 and Norwegian protocols (Riksantikavaren 2008). Once described in detail, the descriptions and urban stratigraphy were simplified to establish a small number of categories to aid the study of typology and expedite geochemical analysis of the sediments. Some of these analyses had formed part of the proposed research design before the project started. Others, however, had to be adapted and incorporated as the project progressed in order to provide standardised and comparable results or to answer specific research questions which arose during an iterative process of data collection and interrogation (including determination of the chronological framework).

Data analysis was aided by a variety of different software. Borehole logs were plotted using gINT (https://www.bentley.com/en). Surfer (http://www.goldensoftware.com/products/surfer) was used in an attempt at 3-dimensional modelling since trials using geographical information systems were found to be unsuccessful because of too few data points. Adobe Illustrator was used to convert digital graphic modelling diagrams into publication standard illustrations (Figure 15.5a,b,c). However, in spite of the availability of a range of software packages, experiment showed that the best method of data analysis was actually to plot results by hand and then convert into digital images by use of Illustrator. Furthermore, the process of undertaking manual transcription of the data required significant engagement with the data during analysis and interpretation and provided a means of identifying and correcting processing faults introduced into the raw data.

The methodology was designed especially for this project, although it adapted techniques deployed for investigations of other sites with waterlogged deposits, mostly from rural contexts. Some of the approaches had been pioneered by environmental investigations from the 1930s to the 1980s in the fenlands of East Anglia (Waller 1994), where peat and silt deposits had been sampled through auger survey and trial excavation. More recent techniques were adapted from monitoring of sites such as Fiskerton (Lincolnshire; Williams *et al* 2008) and Star Carr (North Yorkshire; Boreham *et al* 2011), the Norwegian World Heritage Site at Bryggen (Bergen; de Beer and Matthiesen 2008; Matthiesen *et al* 2008), and a number of Danish meres and bogs (Gregory *et al* 2002). As previously indicated, the Nantwich methodology evolved as the project progressed. For example, the second stage was divided during execution into two sub-stages, enabling lessons learned during the first campaign of borehole drilling to inform the methodology employed during the second stage. This revised methodology included a modification to install dipwells in the borehole voids, in case a further stage of deposit monitoring might be proposed beyond the initial baseline characterization. Since the Nantwich project has been running, Historic England has drafted guidance on urban waterlogged deposits, which proposes a three tier process: i) desk study; ii) ground investigation for baseline characterisation and assessment; and iii) updated assessment following monitoring (Historic England 2016).

The basic approach to methodology and analysis that was developed here was employed by SLR on several other sites during the course of the Nantwich project, including the timber platform at Must Farm in the Flag Fen basin near Peterborough (Cambridgeshire) (Malim *et al* 2015a); Kings Delph and land adjacent to Must Farm (Cambridgeshire); Trident Park (Cardiff); and East India Dock (London).

Figure 15.4: Windowless-sampling rig in operation: getting permission from many land-owners was a major problem. Note the steel liner and Perspex sleeves

15.4. Interpretation

Analysis of the data was undertaken in various ways, including physical description and assessment of sediment permeability, laboratory quantitative analysis for different chemical species, rapid assessment of organic remains through species identification, loss on ignition (total organic carbon) quantification, wood substance (state of preservation) testing, radiocarbon dating of selected samples from top and base of sedimentary sequence, and identification of the character of aqueous deposition through diatom analysis.

Interpretation of the data was an iterative exercise at several levels, and drew on multiple strands of evidence. Multi-disciplinary dialogue and rationalization of terminology were beneficial to clarify the meaning of some datasets and interpretations. Different disciplines use words and phrases in different ways, and achieving understanding and harmonisation across various disciplines can be a challenge because the nuances are not appreciated. Misunderstandings can thus develop quickly between members of the team and external scrutineers. For example, to a layman sediment moisture levels of 50% would not seem to indicate saturation, but to a hydrologist

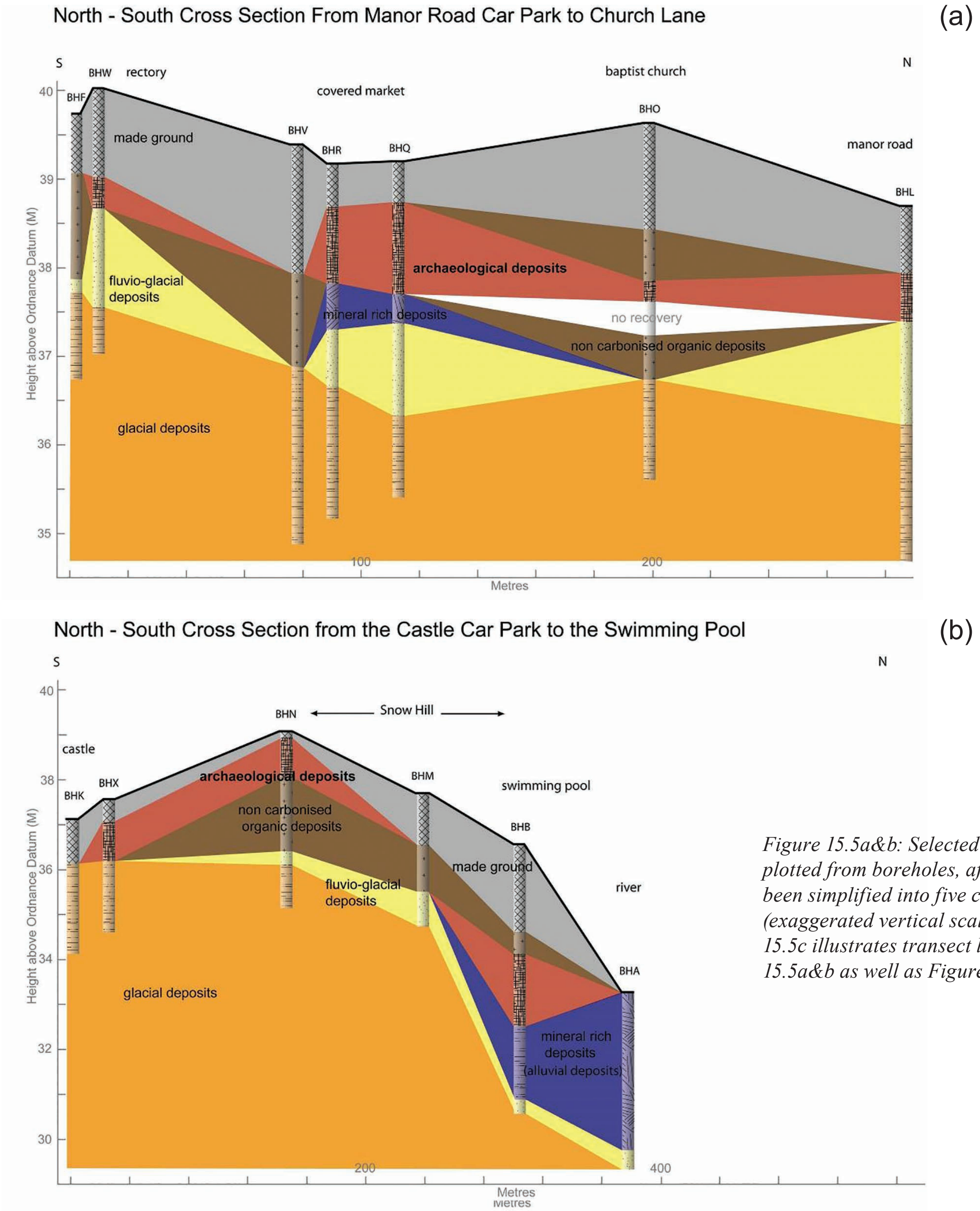


Figure 15.5a&b: Selected transects plotted from boreholes, after logs had been simplified into five categories (exaggerated vertical scale). Figure 15.5c illustrates transect lines of 15.5a&b as well as Figure 15.7.

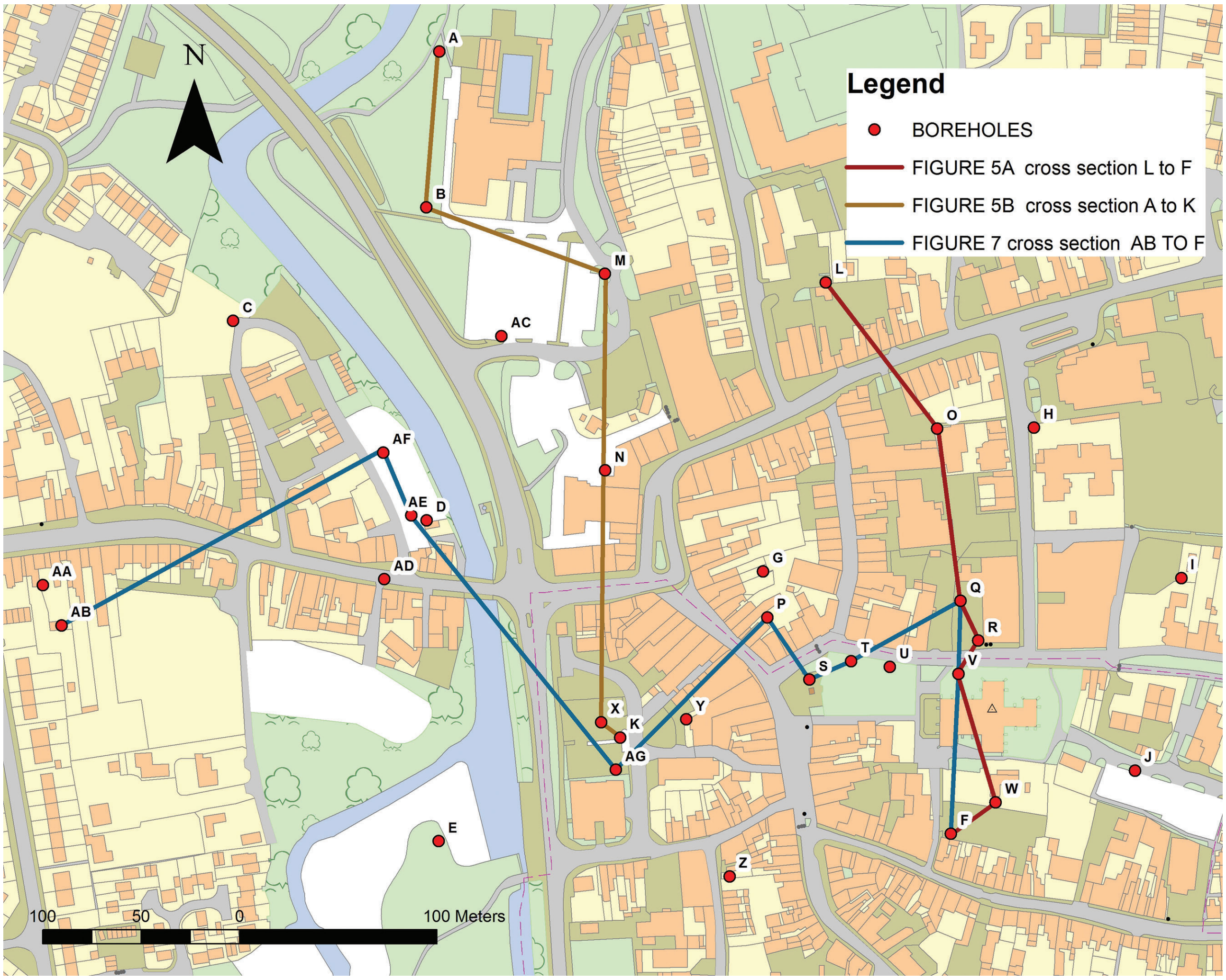


Figure 15.5c

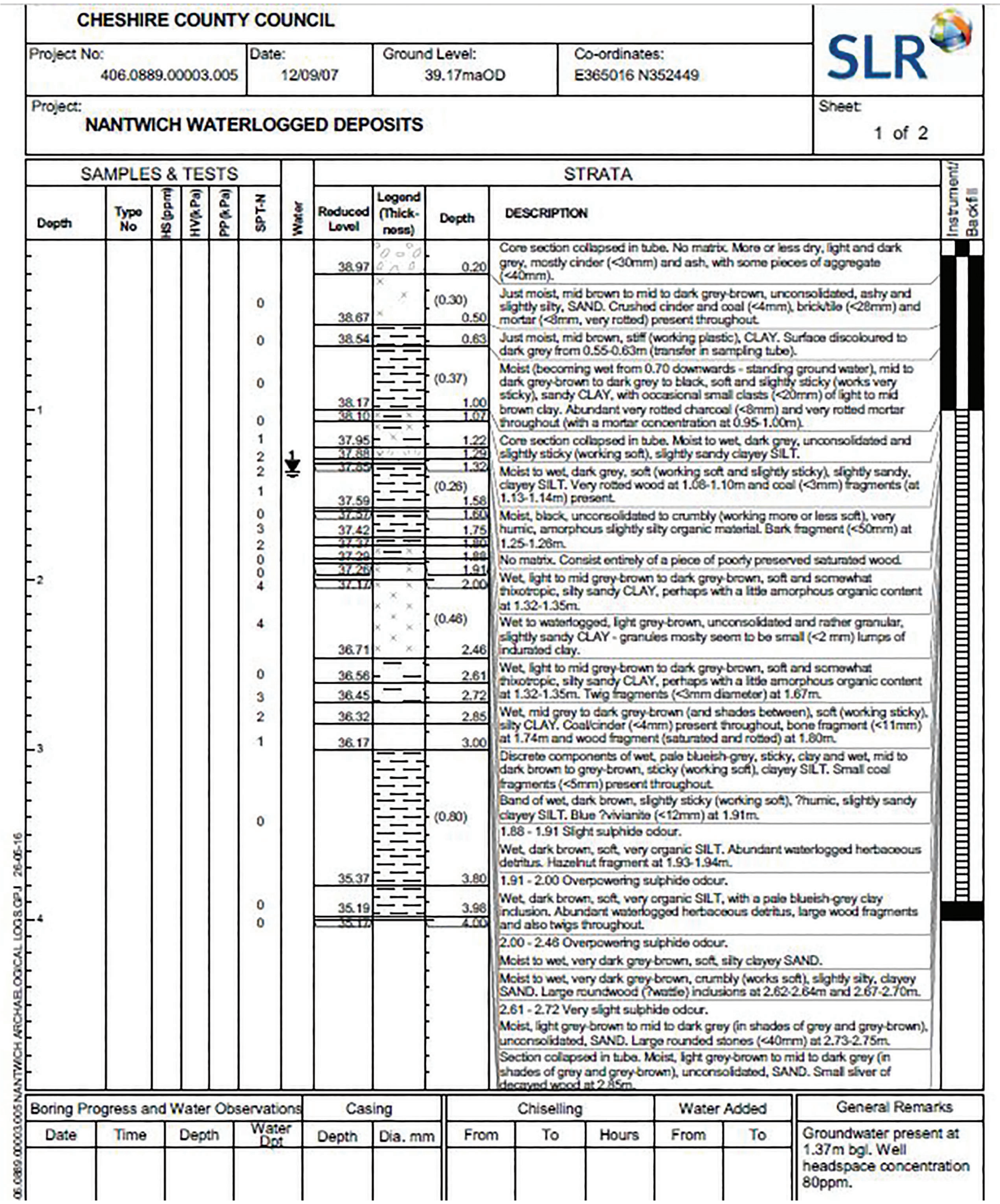
typical expected porosity values for silt (ranging between 35% and 50%) and clays (ranging between 40% and 70%) mean that fully saturated conditions would occur with moisture values of between 50% and 70%.

Basic sediment description can also be susceptible to variations in interpretation, and at Nantwich the need for a valid measure of comparison between borehole logs required a simplification of the detailed geological descriptions. This resulted in a classification of five categories of deposit to which the more complex physical descriptions of the cores could be assigned, thereby allowing transects to be mapped across the historic town as continuous sequences (Figure 15.6a&b).

As a result of the detailed recording of the borehole cores, complicated and diverse horizons and lenses were identified that were often not consistent with other boreholes (Figure 15.6a). Migration of this detailed information to standard borehole logging designed for British Standard 5930 (which categorises all archaeological contexts simply as 'made ground'), complicated the presentation and interpretation of the results and comparison between boreholes. It was decided, therefore, to assign individual lenses from the detailed logs into groups that conformed to one of three categories (organic-rich, mineral-rich or archaeological), to an uppermost 'made ground' category including material of 18th century and later date, or to a 'fluvio-glacial' deposit that represented a sub-division of the lower mineral-rich deposit [see Figures 15.6b and 15.7]):

- Made ground: records from the higher part of the borehole which included brick, mortar, modern materials, or identifiable inclusions datable to the 18th–20th centuries;
- Archaeological deposits: silts, clays and sands, black to light grey in colour, which contained evidence of human activity such as ash, charcoal, pottery and bone;
- Organic-rich deposits with a sulphide smell: non-carbonized plant-microfossils, wood, leather and plant debris;

(a)



CHESHIRE COUNTY COUNCIL

SLR

Project No:	Date:	Ground Level:	Co-ordinates:	Sheet
406.0889.00003.005	12/09/07	39.17maOD	E365016 N352449	1 of 2

Project: **NANTWICH WATERLOGGED DEPOSITS**

Reduced Level	Legend (Thickness)	Depth	DESCRIPTION
38.97		0.20	Core section collapsed in tube. No matrix. More or less dry, light and dark grey, mostly cinder (<30mm) and ash, with some pieces of aggregate (<40mm).
38.67	(0.30)	0.50	Just moist, mid brown to mid to dark grey-brown, unconsolidated, ashy and slightly silty, SAND. Crushed cinder and coal (<4mm), brick/tile (<28mm) and mortar (<8mm, very rotted) present throughout.
38.54		0.63	Just moist, mid brown, stiff (working plastic), CLAY. Surface discoloured to dark grey from 0.55-0.63m (transfer in sampling tube).
38.17	(0.37)	1.00	Moist (becoming wet from 0.70 downwards - standing ground water), mid to dark grey-brown to dark grey to black, soft and slightly sticky (works very sticky), sandy CLAY, with occasional small clasts (<20mm) of light to mid brown clay. Abundant very rotted charcoal (<8mm) and very rotted mortar throughout (with a mortar concentration at 0.95-1.00m).
38.10		1.07	
37.95		1.22	Core section collapsed in tube. Moist to wet, dark grey, unconsolidated and slightly sticky (working soft), slightly sandy clayey SILT.
37.88		1.29	
37.85		1.32	Moist to wet, dark grey, soft (working soft and slightly sticky), slightly sandy, clayey SILT. Very rotted wood at 1.08-1.10m and coal (<3mm) fragments (at 1.13-1.14m) present.
37.59	(0.26)	1.58	Moist, black, unconsolidated to crumbly (working more or less soft), very humic, amorphous slightly silty organic material. Bark fragment (<50mm) at 1.25-1.26m.
37.57		1.60	No matrix. Consist entirely of a piece of poorly preserved saturated wood.
37.42		1.75	Wet, light to mid grey-brown to dark grey-brown, soft and somewhat thixotropic, silty sandy CLAY, perhaps with a little amorphous organic content at 1.32-1.35m.
37.37		1.80	Wet to waterlogged, light grey-brown, unconsolidated and rather granular, slightly sandy CLAY - granules mosty seem to be small (<2 mm) lumps of indurated clay.
37.29		1.88	Wet, light to mid grey-brown to dark grey-brown, soft and somewhat thixotropic, silty sandy CLAY, perhaps with a little amorphous organic content at 1.32-1.35m. Twig fragments (<3mm diameter) at 1.67m.
37.26		1.91	Wet, mid grey to dark grey-brown (and shades between), soft (working sticky), silty CLAY. Coal/cinder (<4mm) present throughout, bone fragment (<11mm) at 1.74m and wood fragment (saturated and rotted) at 1.80m.
37.17		2.00	Discrete components of wet, pale blueish-grey, sticky, clay and wet, mid to dark brown to grey-brown, sticky (working soft), clayey SILT. Small coal fragments (<5mm) present throughout.
36.71	(0.46)	2.46	Band of wet, dark brown, slightly sticky (working soft), ?humic, slightly sandy clayey SILT. Blue ?vivianite (<12mm) at 1.91m.
36.56		2.61	1.88 - 1.91 Slight sulphide odour.
36.45		2.72	Wet, dark brown, soft, very organic SILT. Abundant waterlogged herbaceous detritus. Hazelnut fragment at 1.93-1.94m.
36.32		2.85	1.91 - 2.00 Overpowering sulphide odour.
36.17		3.00	Wet, dark brown, soft, very organic SILT, with a pale blueish-grey clay inclusion. Abundant waterlogged herbaceous detritus, large wood fragments and also twigs throughout.
35.37	(0.80)	3.80	2.00 - 2.46 Overpowering sulphide odour.
35.19		3.98	Moist to wet, very dark grey-brown, soft, silty clayey SAND.
35.17		4.00	Moist to wet, very dark grey-brown, crumbly (works soft), slightly silty, clayey SAND. Large roundwood (?wattle) inclusions at 2.62-2.64m and 2.67-2.70m.
			2.61 - 2.72 Very slight sulphide odour.
			Moist, light grey-brown to mid to dark grey (in shades of grey and grey-brown), unconsolidated, SAND. Large rounded stones (<40mm) at 2.73-2.75m.
			Section collapsed in tube. Moist, light grey-brown to mid to dark grey (in shades of grey and grey-brown), unconsolidated, SAND. Small sliver of decayed wood at 2.85m.

SAMPLES & TESTS: Depth | Type No | HS (ppm) | HV(kPa) | PP(kPa) | SPT-N | Water

SPT-N: 0, 0, 0, 0, 1, 2, 2, 1, 0, 3, 2, 0, 0, 4, 4, 0, 3, 2, 1, 0, 0, 0

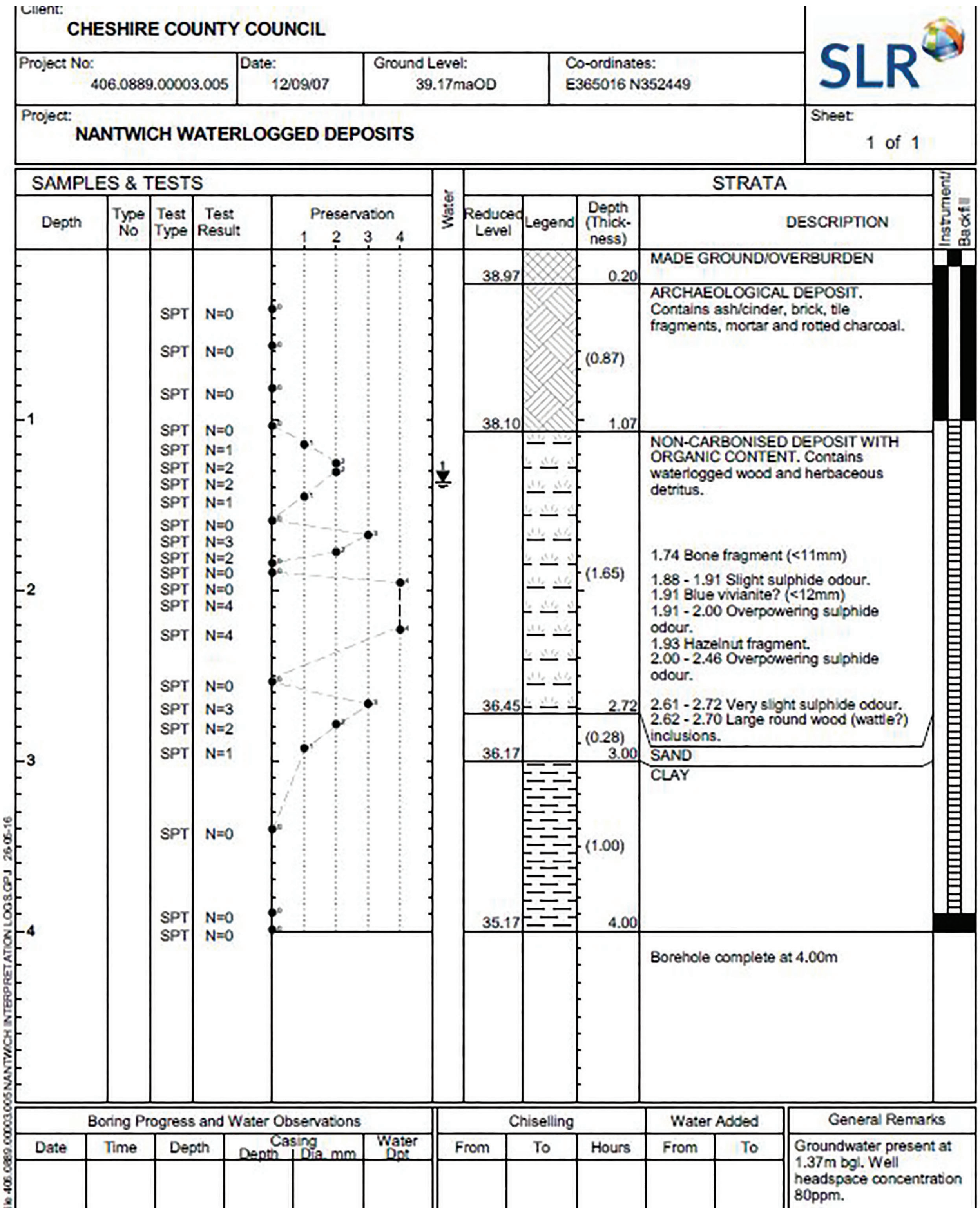
Instrument/Backfill

Boring Progress and Water Observations				Casing		Chiselling			Water Added		General Remarks
Date	Time	Depth	Water Dpt	Depth	Dia. mm	From	To	Hours	From	To	Groundwater present at 1.37m bgl. Well headspace concentration 80ppm.

05.0889.00003.005 NANTWICH ARCHAEOLOGICAL LOGS.GPJ 26-05-16

Figure 15.6a&b: Comparison between detailed archaeological recording of the lenses (6a) in BH N, and simplified version after interpretation into five categories (6b)

(b)


Client:
CHESHIRE COUNTY COUNCIL
SLR
Project No:
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Date:
12/09/07
Ground Level:
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Co-ordinates:
E365016 N352449
Project:
NANTWICH WATERLOGGED DEPOSITS
Sheet:
1 of 1
SAMPLES & TESTS
Depth
Type No
Test Type
Test Result
Preservation
1 2 3 4
Water
STRATA
Reduced Level
Legend
Depth (Thick-ness)
DESCRIPTION
Instrument/ Backfill
1
2
3
4
SPT N=0
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SPT N=4
SPT N=0
SPT N=3
SPT N=2
SPT N=1
SPT N=0
SPT N=0
SPT N=0
38.97 0.20
MADE GROUND/OVERBURDEN
(0.87)
ARCHAEOLOGICAL DEPOSIT. Contains ash/cinder, brick, tile fragments, mortar and rotted charcoal.
38.10 1.07
NON-CARBONISED DEPOSIT WITH ORGANIC CONTENT. Contains waterlogged wood and herbaceous detritus.
(1.65)
1.74 Bone fragment (<11mm)
1.88 - 1.91 Slight sulphide odour.
1.91 Blue vivianite? (<12mm)
1.91 - 2.00 Overpowering sulphide odour.
1.93 Hazelnut fragment.
2.00 - 2.46 Overpowering sulphide odour.
36.45 2.72
2.61 - 2.72 Very slight sulphide odour.
2.62 - 2.70 Large round wood (wattle?) inclusions.
(0.28)
36.17 3.00
SAND
CLAY
(1.00)
35.17 4.00
Borehole complete at 4.00m
Boring Progress and Water Observations
Date
Time
Depth
Casing Depth
Dia. mm
Water Dpt
Chiselling
From
To
Hours
Water Added
From
To
General Remarks
Groundwater present at 1.37m bgl. Well headspace concentration 80ppm.
le 406.0889.00003.005 NANTWICH INTERPRETATION LOGS.GPJ 26-05-16

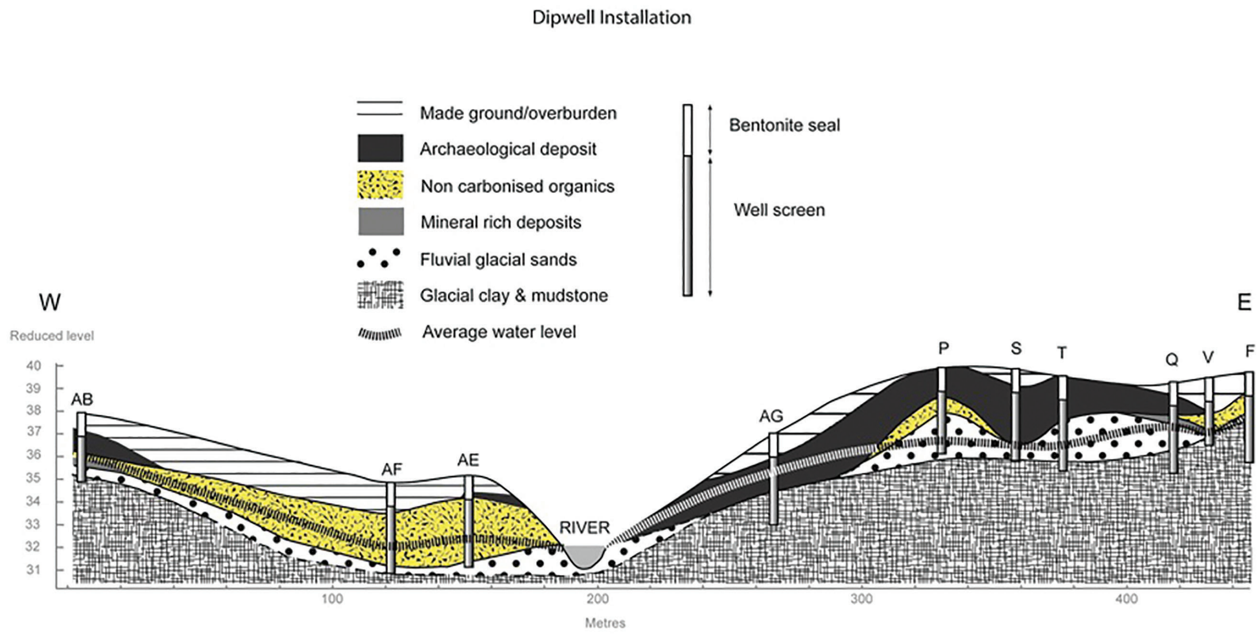

Figure 15.7: Cross-section across river valley plotted from boreholes (interpreted logs) showing saturated sand basal deposit. See Figure 15.5c for location.

- Mineral-rich deposits: grey clays, silts and sands that contained no organic or archaeological inclusions but were not part of the natural superficial geological sequence;
- Fluvio-glacial deposits: records from the lowest part of the borehole, describing sands that represent the top of the natural geological sequence.

A key objective of the project was to identify and map the extent and formation processes for waterlogged deposits and thus the potential for the preservation of organic remains. The identification of surviving organic remains was clearly an important factor. However, other investigations, such as the identification of preservation conditions from geochemical analysis, provided information of equal or greater importance for study of the potential for long-term organic survival in deposits yielding no direct evidence for organic preservation or where associated organic remains had disappeared through decay. The wider inclusion of deposits that preserved more marginal organic content was essential; together with comparison to archaeologically excavated evidence, this helped to identify formerly organic-rich layers in a state of active decay and provided invaluable information on the threats facing well-preserved deposits that survived elsewhere in the town.

A simple summary of 'zones' of potential preservation based on the borehole locations has been established, although additional data points (cores) would undoubtedly help to refine this model in the future. Currently, three categories are recognised:

- Known preservation (where organic preservation is seen to exist);
- Potential preservation (where organic preservation is not necessarily recorded, but where suitable conditions for preservation can be shown or inferred: for example, by a consistently high groundwater level or suitable chemical conditions, and by analogy with other similar deposits);
- No preservation (where organic preservation is not recorded and conditions for preservation are poor suggesting absence).

15.5. Reporting and dissemination

Several papers have been delivered at national and international symposia, together with a number of publications (Malim and Panter 2012; Malim *et al* 2015b; Malim *et al* 2016a) These provide interim statements and comparative studies with related types of site and deposits and complement the final report on completion of the five year programme of monitoring (Malim *et al* 2016b). In addition, five interim reports have been produced to record the results from the monitoring programme annually (SLR interim reports 2011–2015); these reports have been peer-reviewed by the project steering group, which was established at the outset of the project. The need for data compilation and interim report presentation has been extremely beneficial as, together with the challenge and review sessions, it has provided an iterative process; this tested the effectiveness of the methodology and posed research questions as the project progressed, assisting the development of an

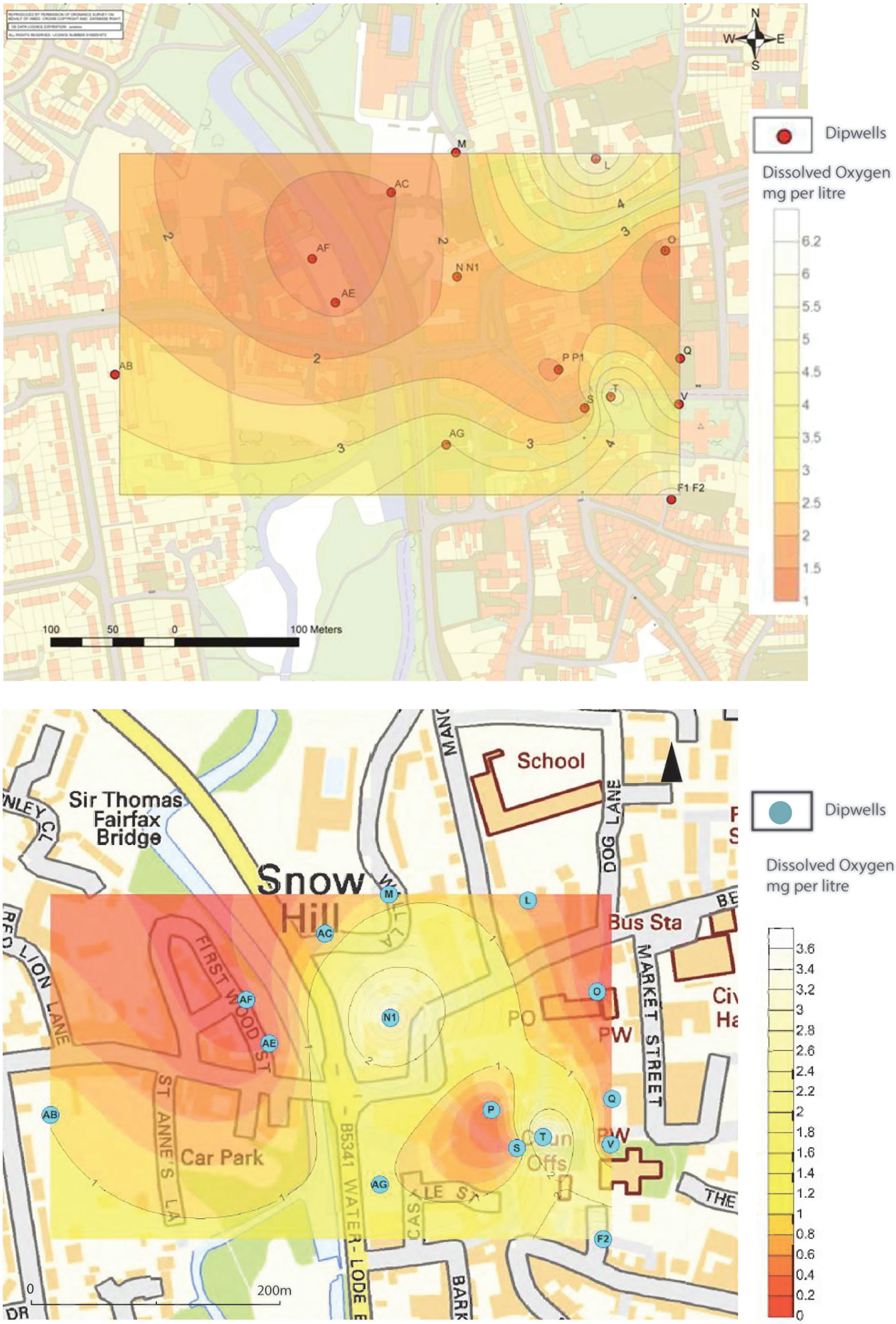

Figure 15.8: Example of data presentation: Plot of gas emissions from monitored dipwells. Upper image is from February 2014; lower image is from December 2015

enhanced methodology and the creation of more robust datasets.

The five years of monitoring have produced a large corpus of data, which is summarised in the appendices of the final report (Malim *et al* 2016b) and remains available for consultation as metadata through hosting on the Archaeological Data Service website (http://archaeologydataservice.ac.uk/). The final report focused on analysis of trends in the data and the interpretations deriving from that analysis. The monitoring data have used proxy indicators to help interpret the degree to which the burial environment enables agents of decay to act on ancient organic remains. These indicators include the degree of saturation within sediments, water quality parameters and the ratios of oxygen-reducing chemical species on a scale from aerobic to anoxic conditions (Figure 15.8).

15.6. Management strategy

The data gathered during the baseline and monitoring programme has provided the foundation for a more detailed understanding of the diverse burial environments of Nantwich. This has enabled development of a sufficiently robust evidence base for design of a management strategy, documented in a Supplementary Planning Document (SPD; Malim 2016). The latter has been endorsed by East Cheshire Council as a supporting document for its Local Plan. The emphasis of this strategy is upon a holistic approach from spatial planners, engineers, developers, utility companies and others whose activities may cause subsurface disturbance and changes in hydrological conditions; this will ensure management of rainfall and run-off in order that water can be stored and absorbed into the ground (Figure 15.9) rather than channelled away from the deposits and contribute to flood risk (de Beer *et al* 2015). By preventing gradual desiccation of the waterlogged archaeological deposits, the strategy will not only help in preserving archaeological remains but will also help prevent subsidence of the built heritage within Conservation Areas such as those of Nantwich. As appropriate, any future development permitted within the Area of Special Archaeological Potential would be required to investigate and monitor the deposits, and data recovered by these means would help to enhance and revise the existing model derived from the project to date.

15.7. Summary and conclusions

The grid of boreholes drilled over the historic core of Nantwich has successfully characterized the deposit sequence for the town, although this interpretive model would benefit from refinement and enhancement as further site investigations take place in the future.

Results from the borehole coring programme and assessment of sediment samples recovered have helped in defining the limits and depth of the waterlogged organic deposits, as well as characterising their physio-chemical condition. Two distinct zones of preservation dependent on local (urban) hydrology have been identified from the geochemical assessment. These comprise a low-lying zone adjacent to the river, in which well-preserved organic remains have been recorded, and a secondary zone along the higher slopes, where organic preservation has been detected but active decay appears to be in progress (Figure 15.10). The evidence for conditions within this latter zone derives from poorly preserved invertebrate and diatom remains, as well as high sulphate and nitrate levels in the deposits liable to fluctuation above the measured groundwater level. Within this zone, however, it was also noted that sulphate levels decreased and sulphide levels increased with depth; below the water-table, therefore, favourable conditions for preservation continue to exist.

Geoarchaeological investigations at Nantwich have pioneered the adaptation of established methods of investigation to establish a baseline for long-term monitoring and study of the dynamic conditions which characterise many urban waterlogged deposits. The project has achieved successfully its objectives and has provided a robust corpus of scientific data that is available for future interrogation and detailed study. It demonstrates how deposit modelling can be taken beyond the study of local stratigraphy and archaeological potential and can inform wider debates focused on the historic environment.

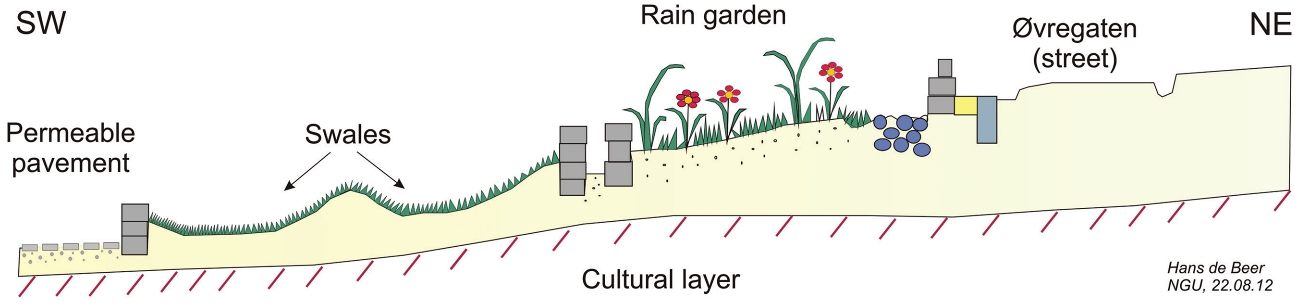

Figure 15.9: Diagram of methods for rainwater capture and recharge in waterlogged deposits, reproduced by permission of Hans de Beer and Anna Seither (de Beer and Seither 2015, Fig. 8.11)

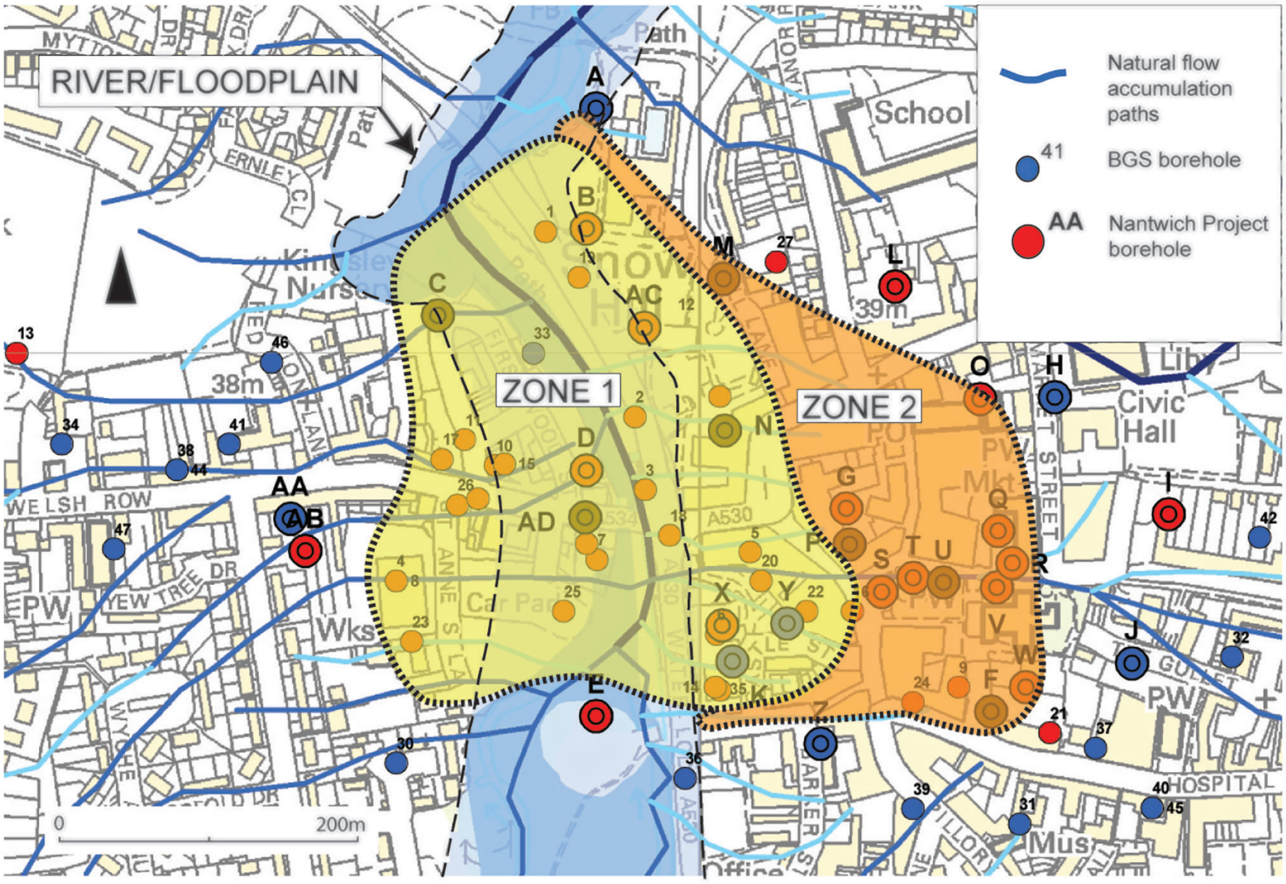

Figure 15.10: Map of Nantwich showing two zones of preservation identified from baseline deposit modelling and dipwell monitoring, with natural flow accumulation paths shown

Acknowledgements

Many thanks are due to Jennie Stopford and Sue Stallibrass (Historic England), and to Dr Jill Collens and Mark Leah (Cheshire Archaeology Planning Advisory Service Cheshire Shared Services), who funded and masterminded the project, steering it throughout Phase 1 (2007–10) and during the five years of monitoring (2011–15). Thanks are also due to all those colleagues who contributed to the project's success, especially John Carrott, Grace Chillingworth, Caroline Malim, John Meadows, Phil Murphy, Ian Panter, Claire Parsons, and especially Mark Swain who played such a major role in designing and executing the borehole and sampling programme.

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Constructing a geoarchaeological deposit model: Nantwich

↓

Assess pre-existing data

- Geotechnical records held by Cheshire County Council
- Geoarchaeological information derived from a variety of watching briefs and other interventions undertaken since the 1970s
- Hydrogeological data and flow accumulation pathways

↓

Develop rationale for model construction and key aims and objectives

- To use modelling to aid the understanding of urban stratigraphy in order to develop a best practice methodology for the investigation and characterisation of waterlogged urban deposits

↓

Can the deposit model be constructed using pre-existing data?

Yes, but the scale is coarse. Data collected from the drilling of 30 additional boreholes as part of this study allowed a more robust model to be created

↓

Commission further ground investigations, including:

- Further purposive boreholes commissioned (n-=30) to allow detailed sediment descriptions and provide sub-samples for dating and environmental analysis

↓

Construct deposit model comprising of one or more of the following:

- Digital elevation models showing key surfaces and units
- Representative cross-sections

↓

Ground truth deposit model through fieldwork and relate back to rationale of commission, aims and objectives

- Initial model revised following purposive borehole survey. Model provided a framework for Phase 2 project, which comprised a 5 year monitoring study

↓

Revise final product

Deposit model integrated with interim and final reporting of project

↓

Archive and reuse

Final report and metadata hosted by the Archaeological Data Service

SECTION 8

Modelling to aid curatorial decision-making

16. A review and case study of deposit modelling in York

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Abstract

Arup and selected partners created a deposit model for the historic core of the City of York in 1989. This model now requires revision and updating. In order to evaluate the scale of work required to update the deposit model, the primary author carried out a sample study looking specifically at the geoarchaeological evidence that could be extracted from grey-literature reports on archaeological interventions in the Bishophill area of York. This case study has demonstrated the significant potential of an enhanced deposit model for expediting effective management and curation of the City of York's archaeological and environmental resource.

16.1. Introduction

The existence of extensive areas of deeply stratified, waterlogged archaeological deposits beneath the City of York, rich in organic artefacts and fragile

Comparative data table of this deposit model	
Deposit model location	City of York (NGR: 460230 451565)
Depositional environment	Urban build-up across Holocene valley floor and adjacent Pleistocene glacial and river terrace deposits
Size of deposit model	Arup study (1991) dataset encompassed an area of approximately 460 Ha. Bishophill pilot study area *c* 18 Ha
Data collection strategies	Review of information collected previously during geotechnical investigations and archaeological interventions reported in the grey literature
Position in the archaeological process	Part of a pilot research study to inform future planning decision-making within the historic urban area
Reason for deposit model construction	To understand the pre-settlement (Roman) topography of York and its influence on human activity and sedentism
Archaeological question	Can geoarchaeological information collected in grey literature over the last 25 years be used to augment and enhance the understanding of the pre-settlement (Roman) topography of York
Software and modelling process	New geoarchaeological information captured from grey literature transcribed into the City of York Historic Environment Record. Data relating to Roman levels exported to ArcGIS where Spatial Analyst function was used to create a Digital Elevation Model (DEM)
Outputs from the deposit model	A series of images was created to aid visualisation of palaeolandsurfaces

palaeoenvironmental remains, has been recognised since the mid-1950s (Richardson 1959). Deposits of this nature have been excavated and recorded in York from as long ago as the late 19th century, but it was only in the later 20th century, particularly following the creation of York Archaeological Trust in 1972, that their extent, quality and archaeological research potential became fully apparent (Hall *et al* 2014). Over the past 40 years, numerous archaeological investigations in the city have encountered such deposits, notably in the valleys of the Rivers Ouse and Foss but also on higher ground, particularly within the area of the Roman legionary fortress; the latter is enclosed by a largely impermeable stone wall, which although buried beneath the medieval defences and modern streets, survives for much of its circuit to a height of 2-3 metres and more (Ottaway 1993).

16.2. The history of deposit modelling in York

A deposit model was created for the city in order to provide a predictive tool for the management of cultural remains within the broader framework of the sediment archive. The model formed a key element of the York Development and Archaeology Study, which was carried out in 1989 and 1990 by Arup, the University of York and Bernard Thorpe and Partners (Arup 1991). The deposit model allowed consideration of the historic core as a single entity and created opportunities for predicting the presence of deposits ranging from prehistoric to modern date. The deposit model was constructed from a database of over 2000 data points derived primarily from archaeological and antiquarian sources, supplemented by stratigraphic information obtained from engineering boreholes. All information within this 3-dimensional archive was tied to Ordnance Datum (metres AOD). The results of this research were presented as a series of maps within the Arup report.

The deposit model formed the foundations for a subsequent University of York doctoral thesis (Miller 1997). Modelling for this subsequent work was carried out using ESRI GIS software (ArcInfo) to create a series of pseudo-3-dimensional land surfaces of key archaeological periods; each surface was illustrated by a ‘wire-frame’ mesh which was modelled using the TIN module (within ArcInfo; Miller 1997). Data points for this work were inevitably patchy, and in some areas very sparse, but no attempt was made to refine the model with reference to detailed consideration of other sources of information such as the modern topography or historic map data. In terms of mapping waterlogged (organic-rich) strata, the collected data offered a simple choice between identifying such deposits as being present or absent; this provided no indication of different degrees of organic preservation within discrete waterlogged units, the wider sediment stack or spatially across the city.

Work on the wider landscape of the Vale of York was undertaken as part of the *Archaeological Visibility and Preservation in the Vale of York Project* (Whyman and Howard 2005) and has expanded and refined our understanding of the stratigraphy of Holocene deposits in the City, including those which are waterlogged. The assessment has provided useful insights into the character and surface morphology of the late Pleistocene and early Holocene sediments that underlie the urban archaeological deposits of the 1st and 2nd millennia AD. These glacial and riverine landforms, which include river terraces, palaeochannels, meres and kettle holes appear to correlate strongly with areas of waterlogging and in some cases have been shown to preserve significant organic deposits.

These new observations suggest that the extent of waterlogged deposits and levels of organic preservation in York are closely linked to the pre-settlement landscape template, which includes landforms that act as significant sediment traps and contain deposits that retain moisture. It is essential therefore that the York deposit model, which in its earliest form is now over 25 years old, is expanded and refined in order to understand more fully and precisely the natural landscape template and the character and origin of overlying deposits, including organic remains.

16.3. A revised deposit model for York

To meet these challenges, the City of York Council is developing a comprehensive and holistic set of management tools for the historic environment in the city. These include the: *City of York Historic Environment Strategy* (in draft, City of York Council 2017); *City of York Local Plan* (in preparation; City of York Council 2017); *City of York Heritage Topic Paper Update* (City of York Council 2013); *York Central Historic Core Conservation Area Appraisal* (Baxter 2011); *City of York Historic Environment Characterisation Project* (City of York Council 2013); and an updated deposit model. The evidence base for these management tools, including the deposit model, is provided by the City of York Historic Environment Record (CYCHER).

The CYCHER uses the Historic Buildings, Sites, and Monument Records (HBSMR) software produced by Exegesis Spatial Data Management (https://www.esdm.co.uk/) to hold data pertaining to the historic environment; this appears as event, monument and source records. Deposit model data is held as event, point and source records in a custom-built table (termed *Stratigraphy*). This data table contains all of the fields that were devised during the collection of information for the 1991 Arup report. HBSMR is linked to ArcMap to provide the GIS component of the CYCHER. In theory, this would allow the data to be visualised and analysed within the 3-dimensional modelling components of ArcMap, but this facility is not currently available within City of York Council.

The City of York Council is currently evaluating the content, software, presentation and interactivity of the CYCHER and as part of this work has prepared a project proposal to update the deposit model data within the CYCHER. In order to evaluate the scale of work required to update the deposit model, the primary author carried out a sample study looking specifically at the geoarchaeological evidence that could be extracted from grey-literature reports on archaeological interventions in the Bishophill area of York. This area, immediately south-west of the River Ouse and within the city walls, is thought to be the site of the Roman civilian settlement (*colonia).* This case study, which includes the development of a deposit model, is described in the following section with the aim of demonstrating the potential of renewed research into the 3-dimensional stratigraphic archive of the city.

16.4. The Roman *Colonia:* topographic study and deposit modelling

Archaeological data, particularly relating to the Roman period has been added to the CYCHER since 2013 in order to improve knowledge of the Bishophill area and to enhance understanding of the relationship between human activity and the pre-settlement topography. The study commenced with a review of data in the HBSMR and linked GIS that had been collected during the Arup project. This was followed by a stage of inputting data assembled from archaeological grey literature reports, most of which have been compiled since 1990 in response to interventions undertaken as part of the planning process.

In order to construct a new deposit model, each data point was recorded in the HBSMR as a separate event. Boreholes and small trenches within each site were treated as separate 'intervention' events within the overall site event. Some trenches generated multiple deposit model entries, thereby increasing the data density (down to 5m intervals where possible). The original deposit model tended to contain one data point for each site or trench, or where possible used a 10m grid to capture deposit model data points. This generated a limited number of data points and therefore a sparse data distribution that impacted on the final resolution of models. Period-specific 'interpretation' data with height (Z) values AOD were then added to the individual intervention events (Figures 16.1 and 16.2).

In order to produce a visualisation of this new data, the Roman data points were supplied to the geoarchaeology team of Museum of London Archaeology. Virgil Yendell (MoLA) writes: *The 'Roman levels' data (568 records) in the York HBSMR were transferred to ArcGIS 10.1, where the Spatial Analyst module was used to create a Digital Elevation Model (*DEM; Figure 16.3)*. A DEM is created on the premise that the height or variable of an unknown point should be predictable by the examination of neighbouring points. The Inverse Distance Weighting (IDW) interpolation tool was used to create a raster DEM. The power of the interpolation was set to 2 in order to reduce the effect of further data points and to preserve landscape features. The distribution of the data that was used to create the model can be described by a K-function (Multi-Distance Spatial Cluster Analysis) but that has not yet been undertaken. There is, however, a general tendency for data points to cluster around sites and to be widely dispersed between the sites. A more detailed review of archaeological GIS modelling methodologies is supplied in Corcoran et al (2011).*

The general Roman DEM (Figure 16.3) shows a concentration of points in the vicinity of the fortress and *colonia*. However, the data for the surrounding area is sparse, resulting in a distorted topography, even the River Ouse valley is poorly defined.

However, the *colonia* part of the DEM, where the additional data has been inputted, shows a much more

Event (site) intervention
(eg NCP Car Park)

Event (data point) intervention, XY values
(eg NCP Car Park borehole 1)

Event (Period) interpretation, XYZ values [One or more (Natural to Modern) as appropriate]
(eg NCP Car Park, Borehole 1, Roman; NCP Car Park, Borehole 1, Anglo-Scandinavian);

Figure 16.1: Event hierarchy for a deposit model data point in HBSMR

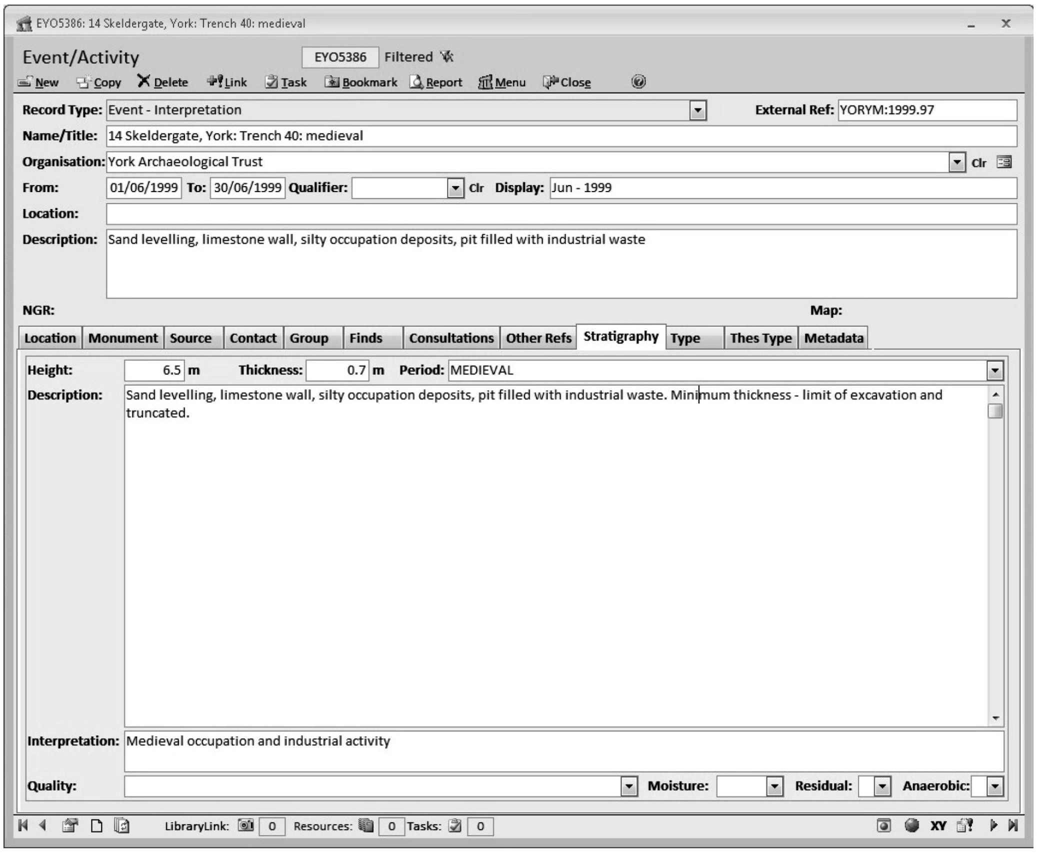

Figure 16.2: Deposit model record in HBSMR

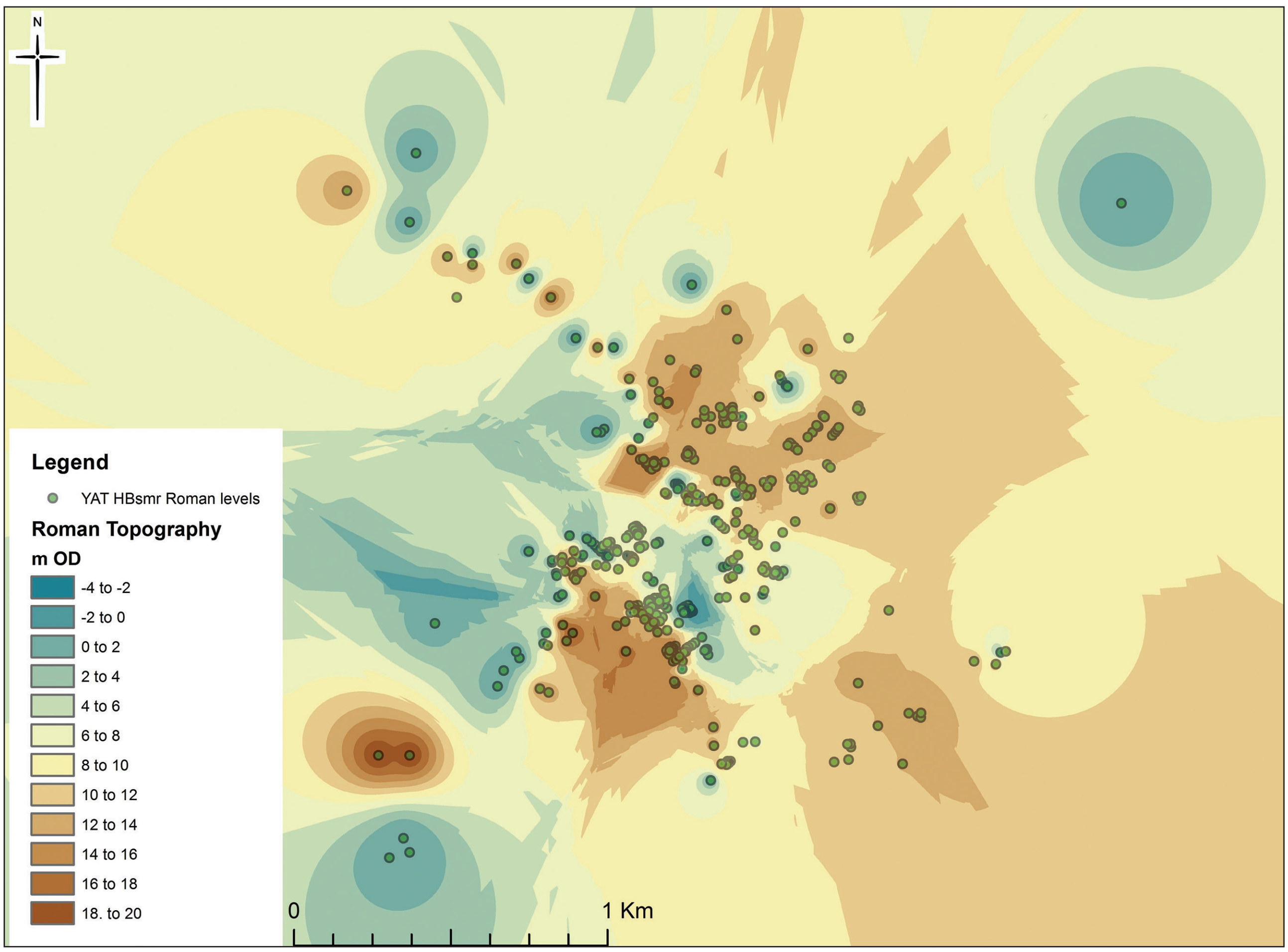

Figure 16.3: DEM of the general Roman palaeolandsurface (working model)

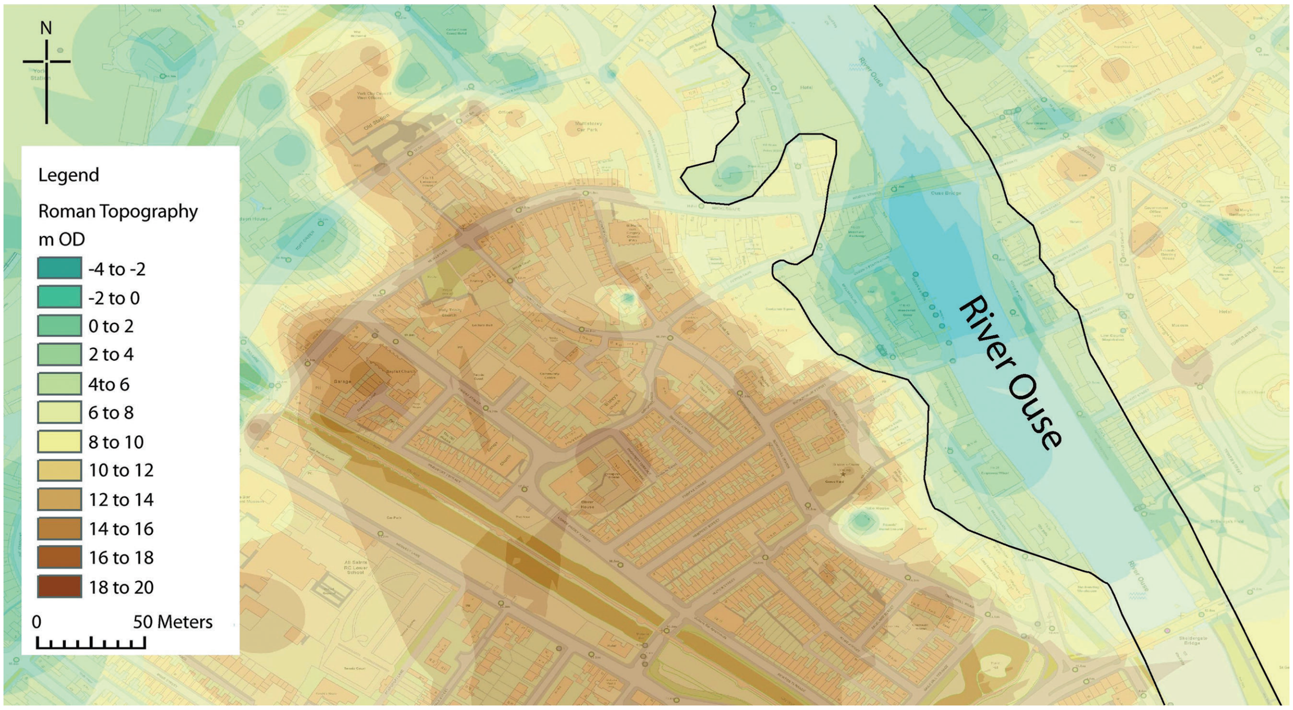

Figure 16.4: DEM of the general Roman palaeolandsurface (working model) Bishophill area, detail

detailed topography (Figure 16.4). It shows a less regular topography than previously thought. The irregular, indented south-west bank of the River Ouse may be due to streams running down from the higher ground. The north-west end of the civilian settlement is generally low-lying, possibly explaining the concentration of early Roman settlement on the higher ground to the south-east. No new data has been added to the north-east of the river during the current study. Such subtleties of the topography, which cannot be observed at the current ground surface, are likely to have influenced the development and character of the Roman settlement as well as the preservation of waterlogged deposits. Identifying areas where cultural and environmental remains are juxtaposed provides real opportunities for reconstructing the archaeological record.

16.5. Challenges for deposit modelling in York

Structure and classification of ArcGIS

Deposits within stratigraphic sequences recorded during archaeological investigations are usually assigned a date that allows them to be considered as part of a discrete archaeological period. Geotechnical records, however, usually have no dating control unless the ground investigations have been commissioned for archaeological purposes (when artefact and/or scientific dating may be applied). Therefore, with the majority of geotechnical site investigations, deposits can easily be assigned incorrectly to cultural periods, especially if deposits are labelled simply as 'made ground'.

The current period structure may allow general conclusions to be drawn from the deposit model including for example, identification of the top of the Roman deposits. However, it does not support more detailed landscape analysis, such as the identification of changes in land-use between the earlier and later Roman periods. The period categories require reviewing therefore if the Holocene development of the river valleys in York is to be evaluated systematically and in detail. The classification of the marginal zone alongside the river also requires consideration in order that the impacts of flooding and tidal processes during the Roman period can be properly assessed.

Quality of fieldwork data

The deposit model for York is based on descriptions and interpretations provided in site reports containing highly variable levels of detail on the character and date of subsurface deposits, thus reducing the value of the dataset for modelling purposes. Firm guidance is required on appropriate levels of recording and analysis, especially during watching briefs (where Ordnance Datum values for subsurface layers are often not recorded), and on the scale of investigation. Borehole data provides a useful basis for deposit modelling, especially if derived from a sampling strategy designed for archaeological purposes, but we would argue that the most reliable evidence for land use and site chronology is provided by excavations of at least 9m^2.

Data distribution

The archaeological data for Roman York is concentrated near the riverside, where most of the recent developments and hence interventions have taken place. There are gaps in the record, often exacerbated by the lack of data underneath existing roads, leaving the possibility of perched organic deposits. Where possible, opportunities should be taken to broaden the distribution of data points as part of site evaluations and ensure the collection of appropriate samples for environmental analysis and dating. Given the small-scale of likely interventions, these will probably take the form of boreholes, but in certain circumstances it might prove necessary to undertake hand excavation to depth.

Data Inputting

The DEM that has been developed as part of this new study is very much a working model and would benefit from further analysis of some data points as well as the addition of more data. For example, several low points, illustrated as blue areas on Figure 16.3 have proved to be artificial interpolations of the data; in the original database zero values had been added to the 'height' cell of some data points where the Roman height value was unknown, whereas they should have been left blank.

16.6. Conclusions

This case study has demonstrated the significant potential of an enhanced deposit model for expediting effective management and curation of the City of York's archaeological and environmental resource. It is also clear that predictive modelling can promote and inform research into York's Holocene deposits, including studies of prehistoric, Roman and later land-use, albeit perhaps on a smaller-scale than is the case in the numerous studies that have been undertaken within urban areas elsewhere, particularly London. It is hoped that it will be possible for future researchers to undertake deposit modelling via the HBSMR, using appropriate software. It is envisaged that the proposed enhancements of the CYCHER and the York deposit model will provide an appropriate and effective framework which can be used to: (a) assist the preservation of deep waterlogged deposits; and (b) deliver significant public benefits by fostering best practice in the recording and analysis of preserved deposits and enhancing understanding of the archaeological and palaeoenvironmental resource.

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17. A planning development management perspective: deposit modelling in south London

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Abstract

Much of the natural low-lying topography within Greater London, and in particular the Thames floodplain, is invariably obscured by a thick layer of urban archaeology and/or modern made-ground, overlying historic estuarine alluvium; this stratigraphy provides little indication of the prehistoric landscape that lies buried potentially many metres below the current ground surface. In such scenarios, evaluation and where necessary mitigation by geoarchaeological techniques can be of great value. These techniques include the assessment of geotechnical logs; the drilling of purposive geoarchaeological borehole cores; and description and interpretation of sedimentary sequences exposed in deep shafts. On a site by site basis, these approaches can enable a clearer understanding of archaeological potential and, when information is pulled together into deposit models, it can be a powerful

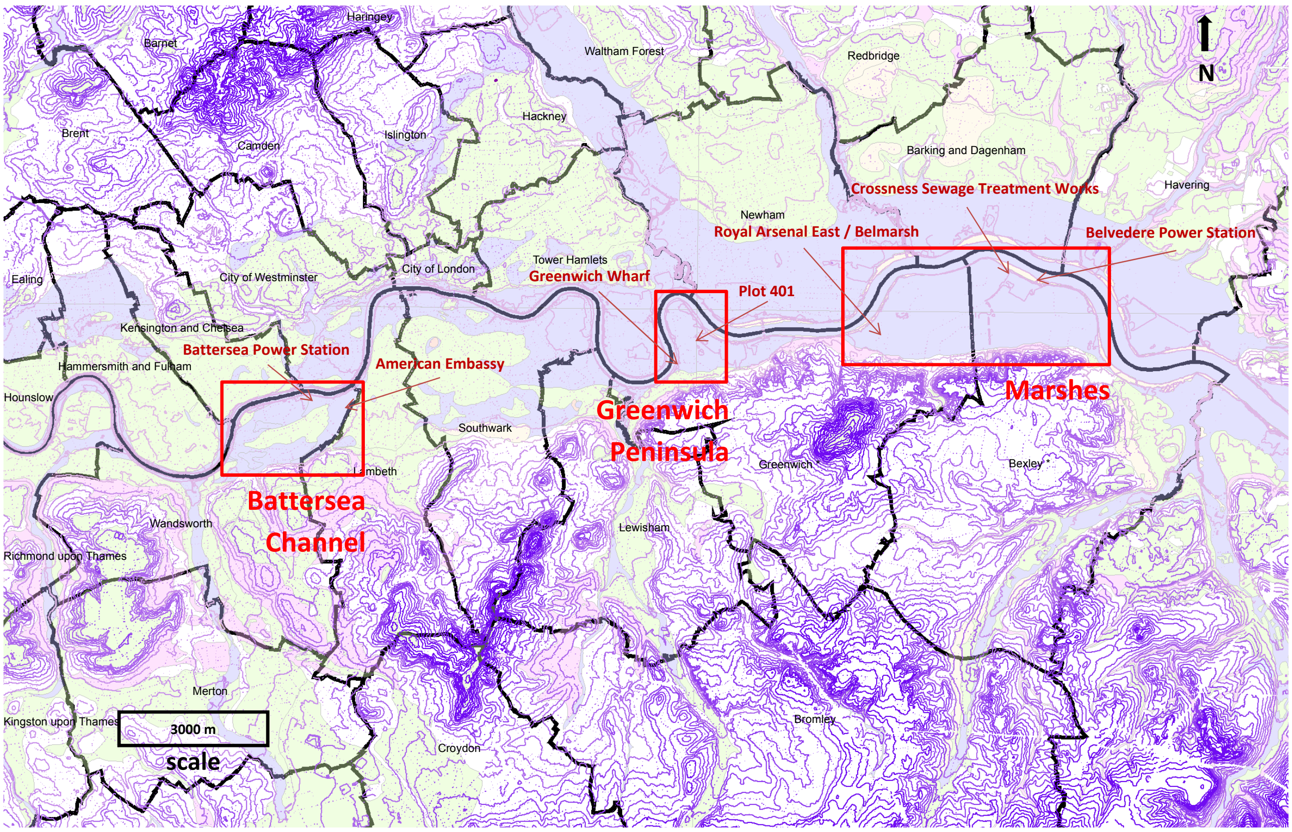


Figure 17.1: The geographic and physiographic context of the three case study areas of south London discussed within the paper, including site specific locations. Information provided by the Greater London Historic Environment Record

tool for understanding the significance of the buried archaeological resource and landscape evolution. Within Greater London, the standard planning conditions can be used with geoarchaeological requirements highlighted when appropriate to ensure such techniques are applied on developer-funded sites. In this paper, I explain why this strategy is justified as one of the standard range of options available to the development control archaeologist in understanding a site's significance and managing its archaeological potential. The staged approach to geoarchaeological investigation and mitigation outlined here has generic application in similar topographic environments beyond London where deeply buried archaeological remains may be recorded.

17.1. Introduction

As an Archaeology Advisor in the London office of the National Planning Group of Historic England, my role is to provide archaeological planning advice to local authorities across nine of the south London boroughs, as well as to developers, consultants, utility companies, national and regional government agencies and local interest groups (https://historicengland.org.uk/services-skills/our-planning-services/greater-london-archaeology-advisory-service/). I am, therefore, able to act when gaps in our understanding of geographic areas or temporal periods become evident, as opportunities arise through development pressure, rather than being confined by client needs to a specific site.

The northern edge of the boroughs that I cover includes a *c* 49 km length of the River Thames and its valley floor. Historically, this area of floodplain has been systematically reclaimed from seasonal flooding by building the land up and extending into the main channel; today, this land is prime 'Real Estate' and in consequence subject to huge redevelopment pressures. Given the complexity of the stratigraphic processes resulting from anthropogenic reclamation and natural patterns of erosion and sedimentation, geoarchaeological advice, including the construction of deposit models, is critical for understanding the archaeological potential of sites within this area. In this paper, I highlight three areas of south London where geoarchaeological techniques have been applied in different ways; each has evolved into an approach of wider generic value (Figure 17.1).

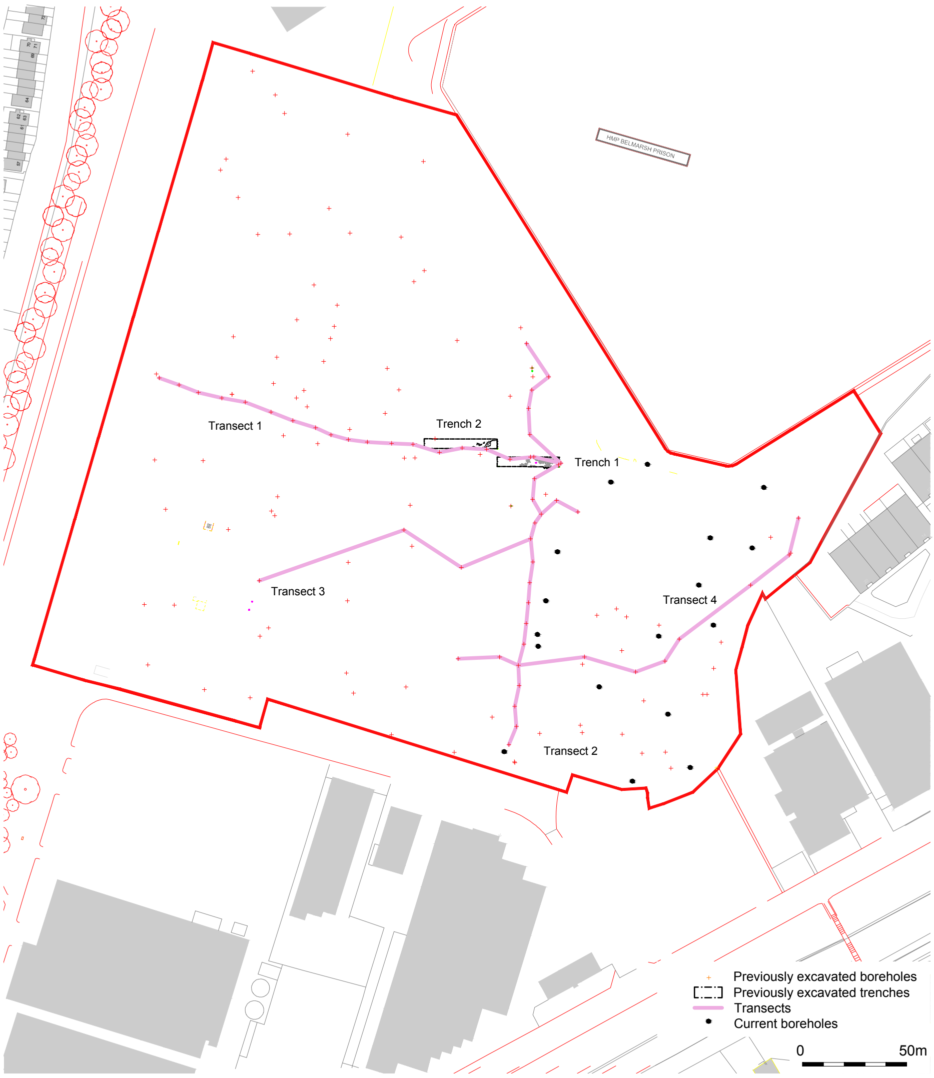
17.2. Case study 1: The Marshes

The extensive floodplain of the lower Thames to the south of the river around Plumstead and Erith Marshes covers some 1,200 ha. Development opportunities immediately across the river to the north, notably in the Lea Valley and its environs in response to regeneration of the 2012 Olympic site, have generated significant volumes of data about landscape evolution and the associated archaeological record. In contrast, I was acutely aware that the southern marshes were by comparison poorly understood. As a result, over a 10–15 year period I have been promoting the combined use of geotechnical and geoarchaeological data on a site by site basis as the means of identifying the potential for cultural evidence. Whilst many of the sites have not yielded significant archaeological evidence, a large body of geoarchaeological data has been amassed which is now sufficient for detailed landscape analysis. A gratifying development in recent years is the growth of independently funded research of this area by Quest at the University of Reading; members of this organisation are currently expanding this body of data with the aim of reconstructing the former landscape and examining its geoarchaeological and palaeoenvironmental potential (R. Batchelor, pers. comm.). Similar work, specifically to reconstruct the buried Early Holocene topography of the Thames and its tributaries in central London, is also being carried out by the Museum of London Archaeology (MOLA) as part of their Crossrail work along the Elizabeth Line (Spurr 2017). The final form and accessibility of these datasets and the models constructed from them, beyond the immediate project teams, is an important issue currently not resolved. While both might be deemed valuable for commercial gain and/or research value, they have considerable potential for wider heritage management; as an aspect of the site archive, the information should be accessible as a layer on the Historic Environment Record (HER), or in some other GIS-based format. While the transfer of such information as point data will enable it to be a live and expanding resource, the planning development archaeologist would prefer an annotated map to inform their planning-related recommendations. A decision may therefore be required of HER managers in terms of whether HERs hold either point data or interpretative maps, although planning archaeologists are more likely to require a combination of the two.

Due to the depth of made-ground, particularly on sites close to the river, investigation of the potential for archaeology by trenching has often proved to be problematic. Pre-Construct Archaeology Ltd investigated two adjacent sites close to the Thames, using different methods in response to the needs of the developer. At Belvedere Power Station, investigation of the subsurface was achieved by the excavation of nine *c* 10m-deep shafts (Mayo 2007a). Three-quarters of each shaft area was machined in spits, while the fourth quarter was dug by hand. This confined work required significant safety issues to be addressed by the use of a personnel cage on a crane; archaeologists were attached to the cage by harness so that in an emergency they could be pulled up quickly as the cage was raised (Figure 17.2). The same depths of sediment needed to be investigated at the neighbouring site of Crossness Sewage Treatment Works (Mayo, 2007b), but at that site an open-cast approach to exposing sediments was adopted (Figure 17.3); this negated the

Figure 17.2: A combination of long-reach machine and hand excavation within a shaft to the base of the peat, Belvedere Power Station site, Bexley (October 2007). Photo courtesy of Historic England

Figure 17.3: Machine 'open-cast' excavation of peat deposits, Crossness Sewage Treatment Works, Bexley (September 2007). Photo courtesy of Historic England



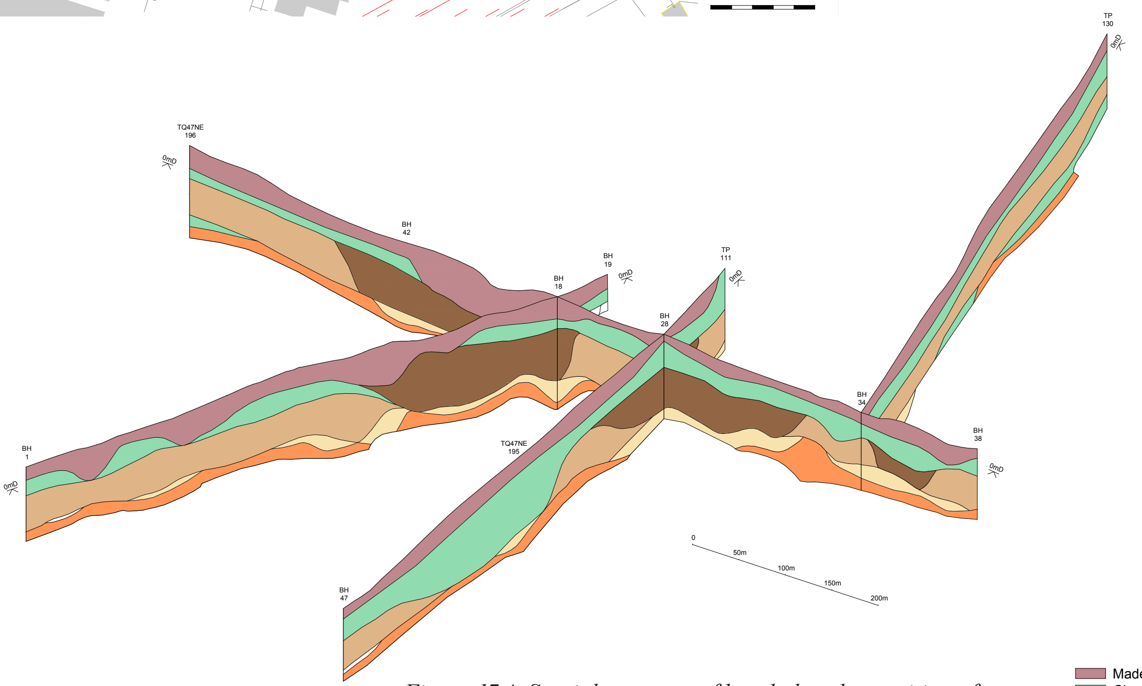


Figure 17.4: Spatial coverage of boreholes plus position of transects used to construct 'fence' diagram, Former Royal Arsenal East site, Plumstead. This information was used to inform the redevelopment of the site as a juvenile detention centre, south-west of HMP Belmarsh (© M Bates)

Figure 17.5: A view of the two archaeological mitigation staggered trenches, Former Royal Arsenal East/Belmarsh West site, Thamesmead (September 2008).
Photo courtesy of Historic England

Figure 17.6: A view of the hand-excavated peat at the east end of the eastern trench, Former Royal Arsenal East/Belmarsh West site, Thamesmead. The plate shows the baulk left along the side of the trench to provide a continuous 65m record of the detailed changes identified within the peat sequence (September 2008).
Photo courtesy of Historic England

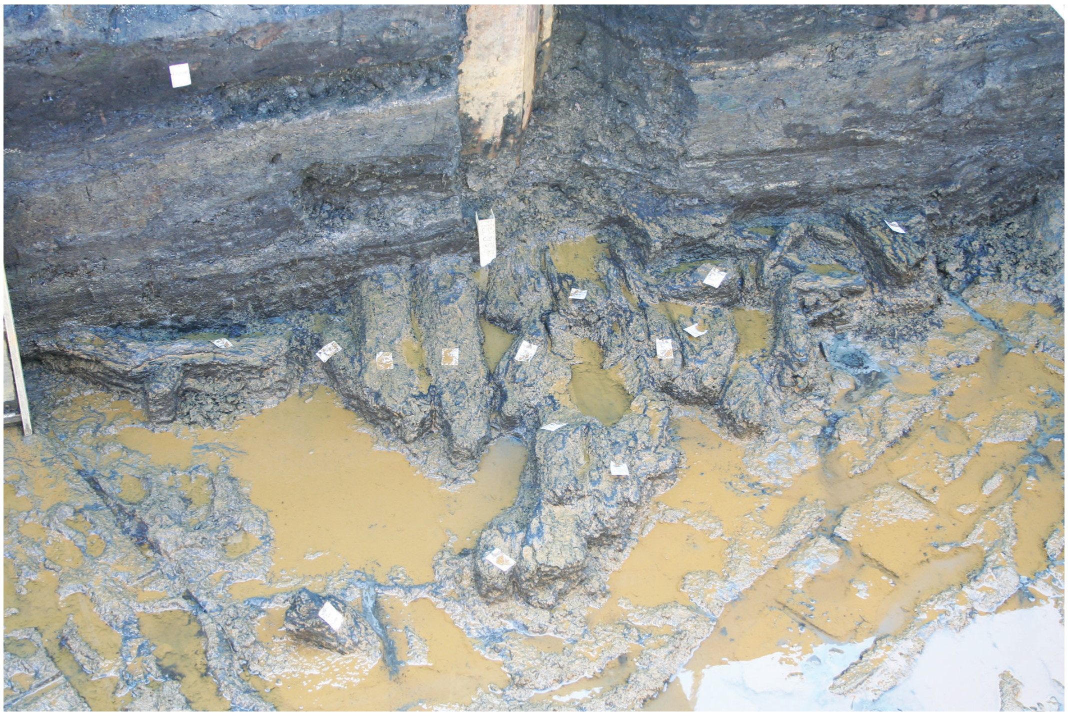


Figure 17.7: Neolithic wood remains identified close to the base of the peat horizon, Former Royal Arsenal East/ Belmarsh West site, Thamesmead. The remains consisted of split timbers laid in pairs. Photo courtesy of Historic England

need for the previous health and safety measures, as well as ensuring that any gas emitted by the exposed organic-rich sediments would quickly dissipate. Interestingly, the cost of the two approaches was broadly comparable, but the open-cast approach proved more efficient as time was not required for the insertion of sheet piles before the commencement of each shaft excavation. Although the open-cast approach was good for recording sediments, as relatively large exposures of *in situ* deposits could be seen in section, it is a comparatively crude method for the retrieval of artefacts. It also required sufficient space for excavation and for storage of the large volume of spoil that was generated.

Geoarchaeological investigations were also conducted towards the western edge of Plumstead Marsh on the site of Royal Arsenal East: a cluster of sixty-six 20th century buildings next to Belmarsh Prison that was scheduled for development as a juvenile detention centre (Fasham 2008). Following full building recording and demolition, the geotechnical data was reviewed; geoarchaeological boreholes were drilled to sample significant gaps in the spread of geotechnical boreholes and to investigate areas of interest or anomalies that were identified in the geotechnical record (Krawiec and Bates 2013). The resultant deposit model identified where site-wide transects would be desirable (Figure 17.4). In total, two transects consisting of 41 geoarchaeological boreholes spaced at 10m intervals were drilled. The cumulative result of this work was the identification of three locations where trenching was perceived to have a high potential for *in situ* archaeology. Following discussions with the contractors and their client, two 4m-wide trenches were excavated in areas that were deemed to have the highest potential for the preservation of archaeological remains. These staggered trenches extended for 30m and 35m, and were set at right-angles to the edge of an identified palaeochannel. The cost and time involved in excavating these deep trenches, which sampled less than 0.5% of the site, meant that this was to be the only mitigation approach that would be applied to this site prior to development (Figure 17.5). However, this detailed work did permit the identification of *in situ* Bronze Age and Neolithic remains, enhancing thereby our understanding of the site and the potential for neighbouring sites (Figures 17.6 and 17.7; Hart *et al* 2015). The identified archaeology led to a revision of the foundation design to permit preservation *in situ* of the archaeology within the site. Such positive results would not have been achieved by random shallow trenching, but they were made possible by a staged programme of boreholes, geoarchaeological assessment and modelling.

17.3. Case study 2: Greenwich Peninsula

This *c* 80ha peninsula in the Royal Borough of Greenwich was the subject of a Masterplan developed in 2004 by Meridian Delta Ltd; in response to this document, Historic England (then English Heritage) submitted an archaeological brief to address the potential of the site. As part of the Masterplan application documentation, MOLA (Corcoran 2002) had prepared a detailed deposit model of the peninsula using the records of hundreds of geotechnical boreholes and information from previous archaeological investigations (Figure 17.8). This approach worked up to a point, but it did not permit the deposit model to be maintained as a live and evolving database.

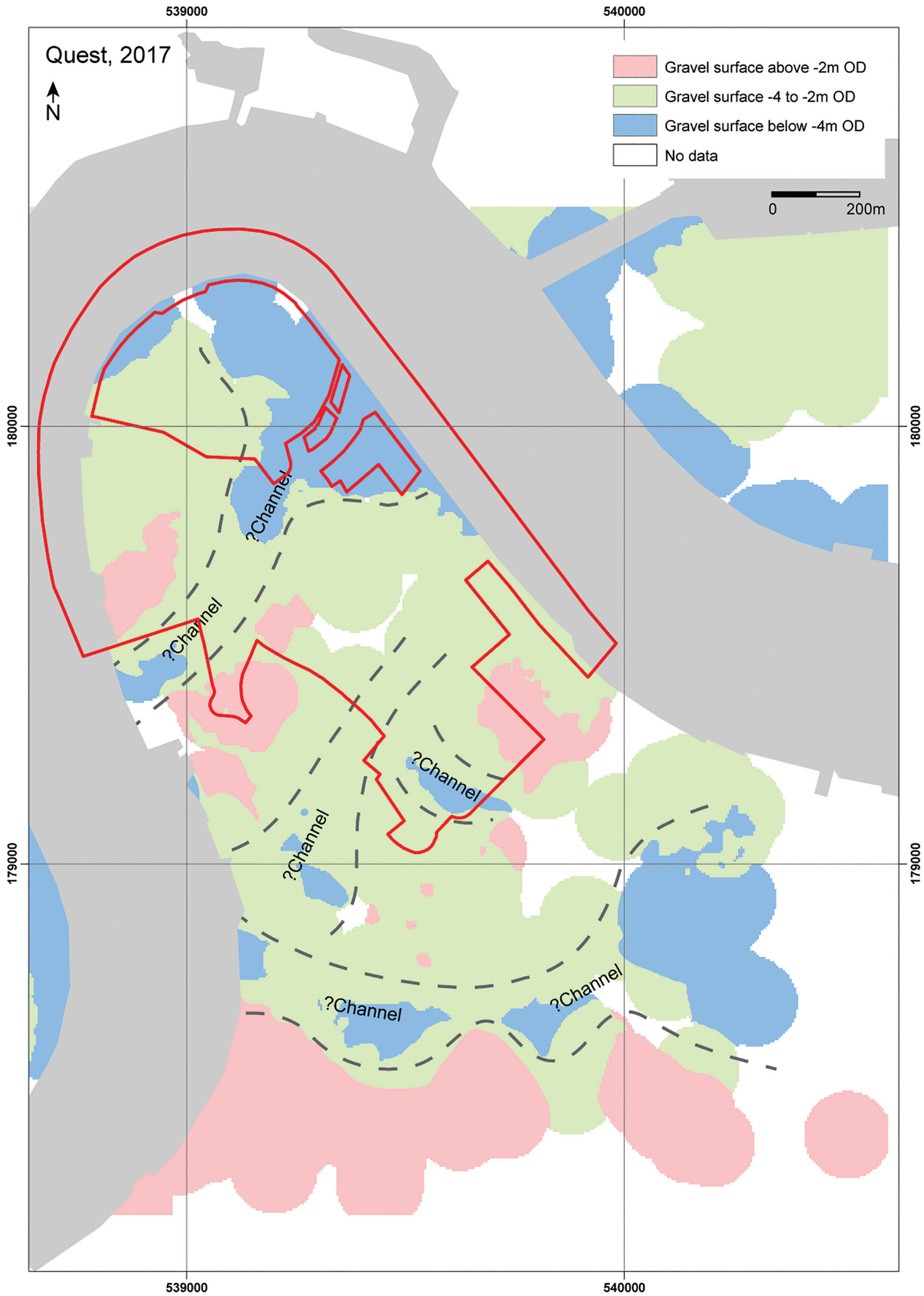


Figure 17.8: Outline in red of the Greenwich Peninsula Masterplan area superimposed with the 2017 version of the Quest deposit model (© Quest). The model shows the buried ancient landscape with suggested channels dissecting the area. The model was generated by using 100m radius of interpolation around each borehole record, rather than a standard 50m radius routinely used by Quest. This decision with respect to interpolation was taken to better visualise the broad topographic features, though a 50m interpolation will be used to evaluate additional data

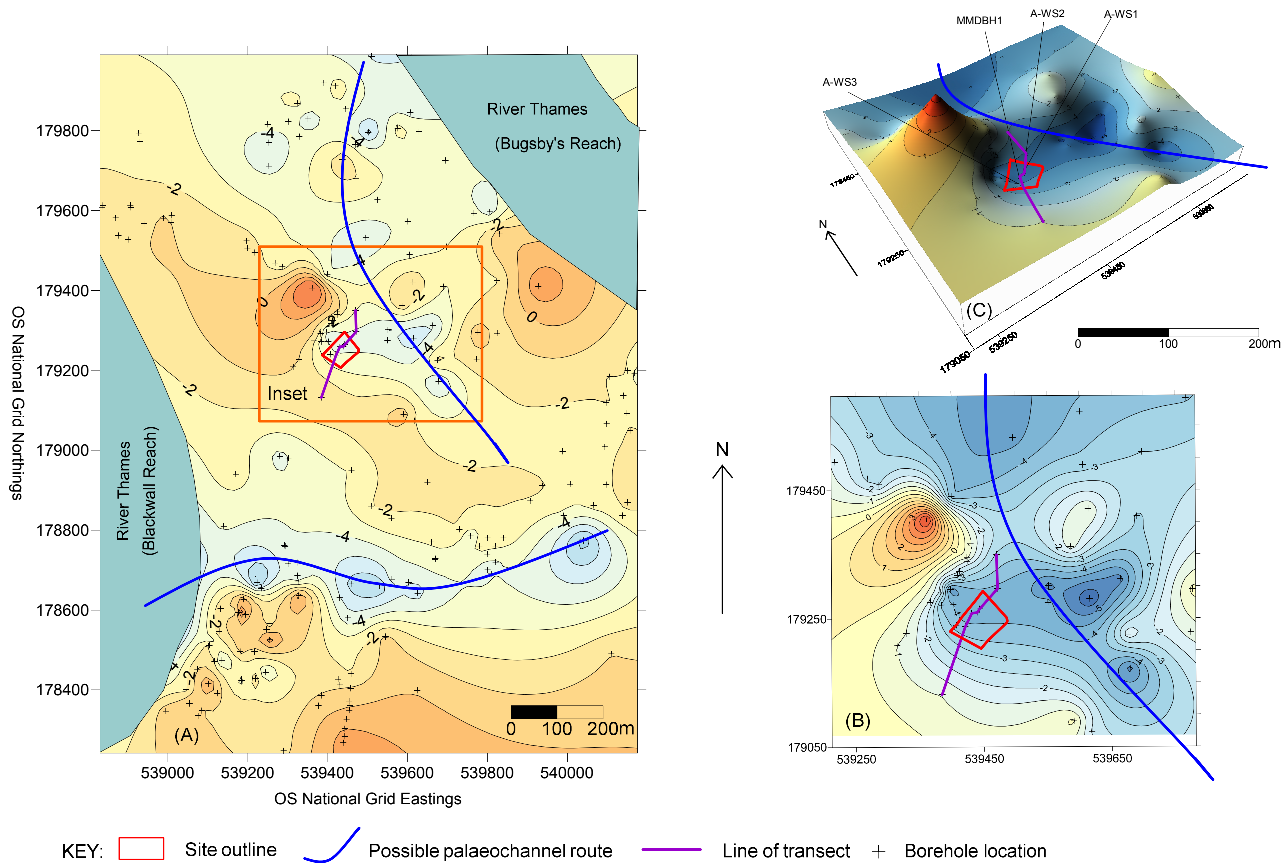


Figure 17.9: Deposit model of Plot 401, Greenwich Peninsula, placed within its immediate area, an amalgam of geoarchaeological and geotechnical data (© MOLA)

Furthermore, the archaeological brief set a trigger level of 5% of a site's footprint that needed to be impacted by piling before archaeological intervention was required. Investigation of potentially deeply buried gravel highs was therefore unlikely. This was frustrating, as the modelling suggested 'islands' of higher gravel beneath the floodplain alluvium that might have served as potential foci of past human activity. Plot 401 (Figure 17.9) is a case in point; here, deposit modelling provided clear evidence of the area's potential, although the options available for further investigation were limited (Spurr 2016).

The peninsula Masterplan was updated in 2015 when the majority of the area remained undeveloped. This provided an opportunity to reappraise the geoarchaeological approach and to revise continually the deposit model strategy, enabling archaeological trench evaluation of identified key locations. An archaeological brief was produced by Historic England (Stevenson and Warman 2016). It was imperative that the developer's archaeological consultant was fully engaged during the process of the briefs' production. As a first stage of the new brief, the MOLA model of 2002 was to be updated by Quest with geotechnical and geoarchaeological information obtained through the investigation of a number of development sites on the peninsula as part of a wider model (Green *et al* in prep). This site-wide deposit model, using 797 borehole records in conjunction with information from the Greater London HER, would enable a preliminary assessment of the archaeological potential of each of the individual development 'plots' that had been identified across the peninsula. As a result, some would be flagged for further geoarchaeological investigation, while others would be excluded on the basis of having sufficient data to determine no discernible on-going potential. This assessment would occur before plot specific development applications were submitted for determination by the Royal Greenwich Borough Planning Authority. Given the outline nature of proposed developments and underlying geology, it is expected that the main archaeological impact would be/will be from piling but could also include the excavation of basements and/or attenuation tanks.

In essence, this strategic approach is more responsive to the archaeological potential of the peninsula, as it is underpinned by a staged strategy that is locked into the planning process. This was achieved when the applicant's consultant submitted to the Royal Greenwich Borough Planning Authority, as part of a planning response, their Masterplan-wide Method Statement that referenced the Historic England Brief (Blatherwick and Batchelor 2017). Following initial assessment, subsequent work might

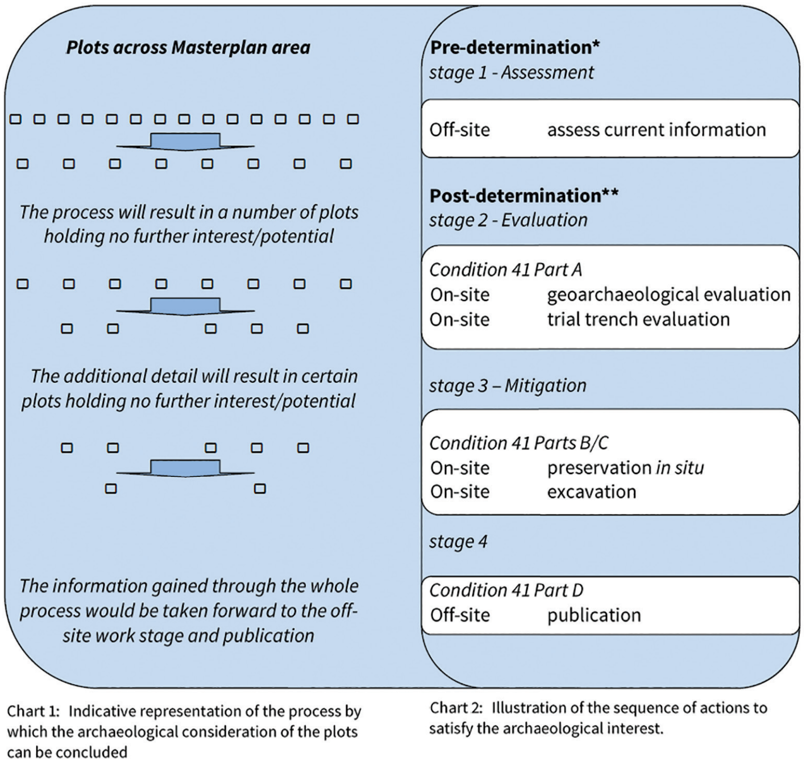


Figure 17.10: The planning chart from the Historic England Greenwich Peninsula Brief that maps the staged archaeological approach designed to lead to the early identification of the key geo/archaeologically important development plots as well as those plots that hold no further geo/archaeological interest. Such information is critical for developers

include purposive geoarchaeological borehole surveys to provide additional information to fill gaps in spatial data coverage and/or to investigate areas of interest identified from existing geotechnical records. This new data would be fed back into the site-wide deposit model (held and managed by the Masterplan archaeological consultant), and would therefore facilitate an update of the bigger picture; it would also identify any archaeological or environmental potential, which could then be considered for targeted archaeological evaluation. Given the potential depth of made ground, this stage of further work would need to be tightly focused and could represent the sole mitigation response for a specific development plot. It is anticipated that only a small number of the original suite of development plots would require limited area excavation. In such cases, the proposed work would be considered in the context of the whole 80 ha site rather than the size of the specific plot under investigation, enabling economically sustainable mitigation (Figure 17.10).

17.4. Case study 3: Battersea Channel

The area of Battersea/Nine Elms, which lies mainly within the London Borough of Wandsworth, consists of prime riverside land that had been dominated by industrial activity typified by the former Battersea Power Station, (Figure 17.11; Figure 17.12). In 2012, it was defined as one of the Mayor of London's (growth) Opportunity Areas, with the aim of building 20,000 new homes and creating 25,000 jobs (Mayor of London 2012). Permission to build the new United States Embassy within this area provided the catalyst for funding of the Northern Line extension, which will serve the planned residential developments via new stations at Nine Elms and Battersea Power Station. The sale in a single weekend of the apartments in the Phase 1 Battersea Power Station development prompted a gold-rush of investors, which in turn, accelerated opportunities for redevelopment. This area of intense redevelopment included the buried eastern end of the relict Battersea Channel: a former route of the Thames with significant archaeological and environmental potential that was first studied (and named) as recently as 2006 during the course of a relatively small-scale development on Stewarts Road (Morley 2009).

The frenetic pace of redevelopment in this area provided an opportunity for joined-up thinking by linking the numerous development sites, within a project where the archaeological practices would be invited to collaborate (Figure 17.13). This initiative, termed the Battersea Channel Project (BCP), provided a viable framework for individual interventions to be considered as part of the greater whole by pooling of site data into the BCP post-excavation programme. The Project was facilitated by Historic England (then English Heritage). Two preceding chapters within this volume (Chapter 7, Payne *et al*; Chapter 11, Yendell) illustrate the approaches undertaken at discrete sites within the BCP area. It is not my intention to duplicate this information here; rather, I wish to provide an overview of how I shaped the process from a planning perspective by developing a Brief for the BCP area that defined a three year data collection phase (2015-17), followed by a year to prepare the outcomes (Stevenson 2014). The two archaeological practices and one consultancy that were already working within the area

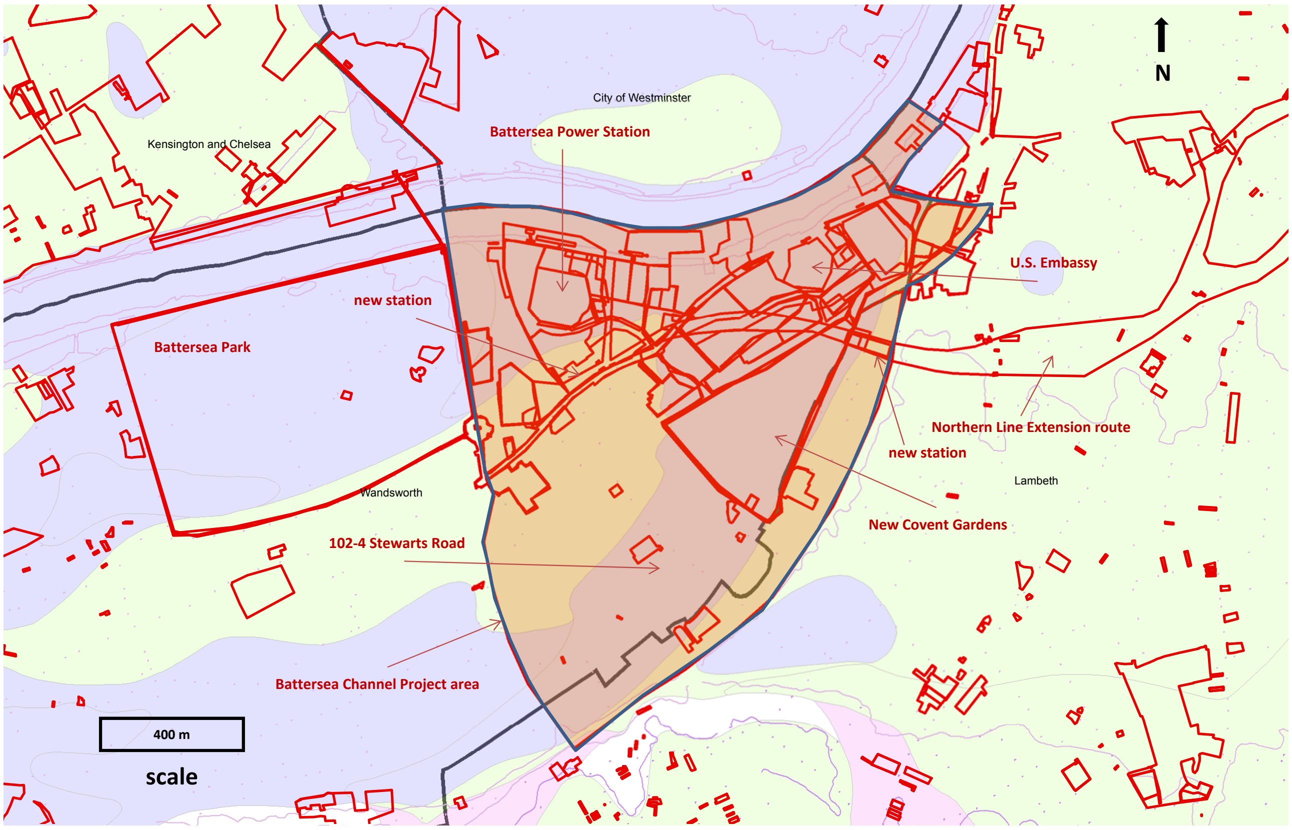


Figure 17.11: Battersea Channel Project (BCP) area shaded salmon pink with some of the key adjacent development sites identified from the Greater London Historic Environment Record

Figure 17.12: Aerial view looking eastwards of the Battersea Channel Project area (October 2009). The area extends eastwards from the edge of Battersea Park to beyond the distant low square building of the Flower Market, part of the New Covent Garden site. From south of the River Thames and its foreshore, it extends to a line along the Wandsworth Road. Photo courtesy of Historic England

Figure 17.13: Illustration of the frenetic pace of development activity within the BCP area at the US Embassy site, Nine Elms (September 2013). Despite the speed of development, the BCP demonstrated that archaeological site work can be undertaken successfully within such environments if part of a well coordinated and robust strategic framework. Photo courtesy of Historic England

Figure 17.14: Forum meeting, Battersea Channel Project (August 2015). Photo courtesy of Historic England

were invited to respond with a joint Method Statement (Batchelor *et al* 2014). Two documents were submitted to Lambeth and Wandsworth borough planning authorities for their support. A Project Board meeting comprising the two planning authorities and Historic England was held prior to the commencement of the project. A Forum was established that consisted of the three archaeological organisations that drafted the joint Methods Statement and more than ten other organisations that have subsequently undertaken work within the project area (Figure 17.14). The Forum chaired by Historic England meets once or twice a year for roundtable discussions, depending upon the rate of accumulation of new data. Collaboration is such that primary data is exchanged before it is presented in 'grey literature' reports to fulfill planning requirements. The final outputs of the BCP will comprise a series of technical papers and a popular-style publication. The Forum is also exploring the legacy potential for a live database to be hosted by the Greater London Historic Environment Record.

A value-added outcome to the partnership working is that the depth of assessment contained within geoarchaeology site reports has increased, along with the development of ways to represent more effectively the data. It has also fostered a 'mentoring' approach by the highly experienced geoarchaeology teams of those companies that are in the process of developing or enhancing their geoarchaeology capability.

17.5. Enhancing planning conditions

The wording of standard planning conditions in Greater London, when expanded, divides into paired statements, the first requiring a written scheme of investigation (WSI) for site work and its execution, and the second a mitigation stage if required. In areas where geoarchaeological data can be expected to form a significant element of site work, the standard planning condition can be enhanced to ensure that the environmental potential of a site is appropriately addressed. This can be achieved by modifying the condition wording to read 'geo/archaeology' (Figure 17.15). This approach helped significantly with the monitoring of development sites in the Plumstead and Erith Marshes, while the Greenwich Peninsula 2015 Masterplan provided an effective mechanism for ensuring consideration of a wider area within the context of a single planning application. A standard multi-part archaeological condition was applied, and supplemented by a detailed brief that articulated how the many development plots would be considered as part of the wider area. This brief produced by Historic England, a third-party, would only gain planning status once the site-wide specification (Blatherwick and Batchelor 2017) that referenced the brief had been submitted by the applicant as a document for the first plot-specific detailed planning application. The brief for the Battersea Channel Project included the wording for a multi-part condition that was modified to contain a specific reference to it; this ensured that all developments within this area had to abide by the Brief and its sister Method Statement and to apply the range of geoarchaeological techniques that these documents required.

17.6. Conclusions

The three approaches described in these case studies show how it is possible to use geoarchaeological techniques as part of a tool-kit approach to understanding past landscapes and their archaeological potential. The risks of development in deeply stratified areas where there is the potential for significant, well-preserved archaeology to be buried at depth can be minimized if development stages include the application of geoarchaeological techniques, which can be seen as a developer's friend. Geoarchaeology has the ability to assess a site without the need to excavate big, expensive holes; it permits a targeted mitigation strategy to be devised that can be demonstrated to be reasonable, proportionate and appropriate, being based upon demonstrable empirical evidence.

On sites without known, tangible archaeological remains, and in particular where the deposits of archaeological interest are deeply buried and likely to be impacted only by piled foundations, it can be difficult to convince developers and consultants that assessment and evaluation of buried deposits is warranted. The geoarchaeological approach, which will provide new information and enhance our understanding of prehistoric landscapes, can often only be taken forward if justification is provided by appropriate planning controls. In addition to geoarchaeological enhancement of planning conditions, it is recommended that the steps listed below be considered in any brief provided by the planning development archaeologist. This should ensure that geoarchaeological assessments and evaluation are included at the most appropriate stages of a project to inform the archaeological investigation of sites to be impacted by development. It should be emphasised that early consideration of the archaeological potential of sites that may form the subject of planning applications is crucial, as stated in the National Planning Policy Framework (Section 12) and the London Plan (2011 Policy 7.8).

Pre-determination of a planning application

Assessment:

- Assess results of historic geotechnical investigations (including data from adjacent sites), with the aim of producing a draft deposit model at the desk-based stage.

Investigation:

- If not undertaken in parallel with geotechnical survey, which would be ideal, geoarchaeological borehole and /or test pit surveys should be conducted

Reason Heritage assets of archaeological interest may survive on the site. The planning authority wishes to secure the provision of
appropriate archaeological investigation, including the publication of results, in accordance with Section 12 of the NPPF.

Condition A) No development other than demolition to existing ground level shall take place until the applicant (or their heirs and successors in title) has secured the implementation of a programme of geo/archaeological *evaluation* site work in accordance with a Written Scheme of Investigation which has been submitted by the applicant and approved by the loca…
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Implementation of a programme of geo/archaeological evaluation site work in accordance with ….

C) A report of the evaluation results will be submitted for approval by the local planning authority which will be given in writing.
D) Dependent upon the results presented under Part C, no development other than demolition to existing ground level shall take place until the applicant (or their heirs and succ… …gical
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Investigation.

Dependent upon the results …. secure the implementation of a programme of geo/archaeological mitigation site work ….

F) The site investigation and post-investigation assessment will be completed prior to one year post the completion date of the development as defined by the borough building regulation officer, in accordance with the programme set out in the Written Scheme of Investigation approved under Parts A and D, and the provision for post investigation assessment, analysis, publication via the **Battersea Channel Project** report and dissemination of the non-Battersea Channel Project archaeological results and archive deposition has been secured.

Informative 1 Written schemes of investigation will need to be prepared and implemented by a suitably qualified archaeological
practice in accordance with Historic England Greater London Archaeology guidelines.
2 The **Battersea Channel Project** is defined by the Historic England over-arching brief supported 10 June 2014 by Wandsworth and Lambeth Local Planning Authorities.
3 Only Section F of the archaeology condition will remain after the completion of the geo/archaeological site work stages.

Figure 17.15: Multi-part condition with the inclusion of a reference to geo/archaeological programme of work

with the aim of enhancing the available geotechnical site data. This should be accompanied by sampling of significant environmental deposits, examination and assessment of inclusions and collection of appropriate samples for dating, followed by refinement of the deposit model; specific cores identified through assessment would only be taken to full analysis if the subsequent stages of site work show this to be appropriate.

- If necessary, further targeted geoarchaeological site investigations (eg borehole and test pit transects across palaeochannels), sample collection and assessment should be conducted, followed by refinement of the deposit model.
- If the potential for nationally or regionally important archaeological remains has been demonstrated, the site may also require further intrusive investigations.

Post-determination of a planning application with the geo/archaeological interest secured by condition

- If impact is only to be from piling: trench to mitigate for cumulative impact.
- If impact from basement, landscaping and/or other spatially extensive construction activities (eg laying of foundations or attenuation tanks): mitigation by strip, map and record of identified key areas.

The potential effect of decontamination and dewatering will need to be considered during all stages of work. This can have an impact upon the decisions to be taken, as well as affecting adversely the potential of archaeological contexts.

For the past 15 to 20 years, the Greater London Archaeology Advisory Service (GLAAS) planning development archaeology advisors have become increasingly aware of the value of geoarchaeological techniques and especially deposit modelling. We have developed and refined our approaches to planning control to make it a requirement that the approach is correct and considered early in the planning process to permit information to be extracted and interpreted from deeply buried deposits. This evolving approach to the potential offered by geoarchaeology has added significantly to our understanding of the prehistoric landscapes that might otherwise be deemed inaccessible and beyond the remit of archaeological investigation. As archaeological planning development advisors, with support from geoarchaeologists, we are in a key position to identify sites or areas with geoarchaeological potential that can contribute significantly to understanding of the development of past landscapes and societies. However, this work is only of value if it is captured by relevant HERs. More work is needed by the contracting sector, in collaboration with HERs and Historic England, to define the level of geoarchaeological information that should or could be recorded in HERs. This will help to define the resources that will be required by HERs to capture and manipulate this specialist information and thus maximize its potential for developing an understanding of the changing landscape and our consultation response to the next planning development application.

Acknowledgements

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SECTION 9

Deposit modelling: towards a unified approach

18. Deposit modelling: application, value, integration and archiving

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18.1. Introduction

The case studies described in this volume illustrate a variety of methodological approaches to deposit modelling that have been developed to increase our understanding of natural deposit sequences that are likely to contain cultural and environmental archaeological remains and associated evidence.

These contributions were presented initially as oral and poster papers at a project workshop held in London in June 2016. As well as the delivered papers, the event also included four break-out sessions aimed at facilitating further discussion of key generic themes that impact on deposit modelling best practice, namely: (1) *the value of deposit models and data integration*; (2) *skills and capacity*; (3) *minimum standards and outputs and;* (4) a*rchives and long-term data-management.*

The 50 or so invited delegates listed in Chapter 19 of this volume were divided into four rotating groups for the break-out sessions, which allowed each group to consider every theme. Discussions were guided by a group facilitator (one of the project convenors) and group recorders captured key comments relating to each; these collected insights provide the basis for this chapter, which aims to highlight common issues and challenges associated with deposit modelling.

Whilst it might be argued that this pre-invited group, composed largely of practicing geoarchaeologists or those with interests and experience of the subject matter, provides a biased outlook, the majority of those invited work within larger heritage organisations and in collaboration with colleagues who have diverse skill-sets and backgrounds, and undertake a wide variety of projects. Therefore, it is considered that these discussions have balance and do reflect opinions shared more widely within the profession.

18.2. Break-out Theme 1: the value of deposit models and data integration

A key question the workshop sought to address was whether deposit models were seen as valuable tools by the wider archaeological community and how they are being applied within the planning and mitigation process. Discussions within all four break-out groups suggest that the application of deposit models is extremely variable across the country, with the majority of studies undertaken in south-east England.

Two major factors almost certainly explain this clustering of activity. The first is the concentration of large archaeological organisations in the region with well-established in-house geoarchaeology teams (many of whom have contributed papers to this volume); this integration of personnel ensures a generally higher profile for such methodologies within these organisations and an appreciation of their value as a mainstream tool-kit available to project managers early on in the planning and design phases of projects. Elsewhere in the country, application of deposit modelling appears to be clustered where experienced local practitioners are available to advise on such approaches to archaeological prospection. The second factor, as illustrated by a number of the case studies presented in this volume, is that the south-east has been the focus of intense economic development during the last decade; this in turn, has resulted in the commissioning of numerous, often large-scale infrastructure projects that require innovative thinking with regard to archaeological prospection, risk analysis and best use of financial and human resources. Given this spatial bias, a key challenge for the heritage community is how to rebalance activity so that deposit modelling becomes standard mitigation practice beyond the south-east.

Emerging national infrastructure projects and other major commercial projects in the Midlands and northern England provide opportunities to apply deposit modelling tool-kits more widely. However, given the nature of competitive tendering, it is essential that if deposit modelling is considered an appropriate tool for any project, then its use must be clearly specified in the tendering process; otherwise, it may be perceived as an additional cost that will make any bid uncompetitive.

Providing curators and other historic environment managers with guidance to promote deposit modelling is critical, though this must be multi-layered to meet the needs of different end-user communities. At a national level, there needs to be the development of generic guidance, which informs heritage practitioners, managers and curators about the subject of deposit modelling and best practice; this in part, will be addressed by the publication of this volume and associated products under the auspices of Historic England. Sitting below national guidance, Regional Research Frameworks commissioned by Historic England could be expanded and/or revised to include more geoarchaeological information which, in turn, could promote deposit modelling and disseminate best practice within discrete areas. This latter initiative could certainly benefit the wider archaeological community since workshop contributors intimated that deposit models were often viewed as applicable only in alluvial landscapes, failing to recognize their potential to guide mitigation within other geological settings where thick sedimentary sequences might also be preserved: for example, aeolian, colluvial and urban contexts. Guidance should also ensure that the wider archaeological community recognizes the potential of using deposit models to inform landscape histories even where cultural remains are absent.

Clear guidance would have the added benefit of identifying at what stage of mitigation deposit modelling should be used; feedback from break-out groups suggested that it was generally introduced much too late in the archaeological process, either as a condition of planning or when the Written Scheme of Investigation (WSI) was being drafted. At both these stages it was considered much harder to produce realistically costed research designs or to influence evaluation/excavation strategies more generally. Appropriate guidance would allow curatorial archaeologists liaising with developers the opportunity to advise on modelling methodologies (including data collation) early on during the project process. This approach could include preliminary modelling during any Desk-based Assessment (DBA) stage; significant sources of geoarchaeological information that could be mined include the field guides of the Quaternary Research Association (www.qra.org.uk), geotechnical records held by the National Geosciences Data Centre (http://www.bgs.ac.uk/services/NGDC/home.html) and developers. However, feedback from break-out groups indicated that it was essential that such tasks are undertaken by appropriately qualified personnel since leaving data collection and interpretation to staff with little or no training in geoarchaeology would invariably produce sub-standard results.

As well as the need for guidance to promote and integrate deposit modelling into the entire archaeological process and to ensure standards are adhered to, it is clear that the community of geoarchaeologists who are usually responsible for creating the models have a significant role to play in ensuring the value of such methodologies is appreciated. This issue is both an internal one to organisations (ie to convince other project managers) as well as an external one (ie to convince clients, their consultants and curatorial officers). With both these internal and external groups, the selling point of a deposit model is that it will save time, money and ultimately reduce risk of encountering unknown remains. For archaeological organisations, this is attractive since it makes tenders more cost-effective and hence competitive; for clients and consultants, reduction of risk of encountering archaeology is the key factor.

It is demonstrable by the success of the large archaeological companies who have led the way in deposit modelling in the south-east, that the methodologies are most successfully applied when geoarchaeologists are embedded within project teams. This provides the opportunity for deposit modelling to be reported as an integral component of a site narrative; presenting the results of deposit modelling as a specialist appendix at the end of a larger report should be discouraged and ideally, it should set the scene for the entire study. Ultimately, to persuade colleagues, clients and consultants to accept deposit modelling as a way forward, the community itself must use jargon-free terminology and language that can be understood by all, not a self-selecting group.

18.3. Break-out Theme 2: skills and capacity

Whilst it is desirable that the archaeological sector is able to construct deposit models, the second break-out theme considered whether staff with appropriate skills-sets were available to undertake such work and what was the nature of capacity. Each of the four groups who discussed this theme flagged the need for geoarchaeological skills. This was viewed as not just an understanding of sediment characteristics and their meaning, in order to make sense of the information available from borehole logs and other geotechnical records, but rather, the archaeological understanding and perspective encapsulated in geoarchaeology (as opposed to practitioners trained in other earth science disciplines). Given the general shortage of geoarchaeologists, the break-out discussions suggested that a greater understanding of soils and sediments and of geoarchaeological techniques, on the part of more traditionally-trained archaeologists, should be encouraged. This might help to identify candidates for training in deposit modelling, as well as encourage a greater take-up of deposit modelling in general, owing to a wider awareness of its value amongst archaeologists.

Project and site managers regularly look at geotechnical borehole and test pit information to gain a quick approximation of made ground depths across a site. It enables calculations of the likely depth and distribution of evaluation trenches and the resources needed to excavate them. This basic appraisal, supported by a quick sketch to help visualise lateral differences in thickness, is essentially a deposit model – and it involves doing what any archaeologist would naturally do to obtain some understanding of what lies below the ground. Therefore, a conundrum has been identified; on the one hand, an argument is being made that only geoarchaeologists or those with a good level of training can construct deposit models, yet on the other hand, recognising that many archaeologists construct deposit models, albeit in a rather more sub-conscious way. If this conundrum is to be resolved, there is a need to define precisely what extra geoarchaeological skills and knowledge a deposit modeller should have and whether an ‘end user’ seeking to apply any model to archaeological questions also needs an in-depth understanding of geoarchaeology and the modelling process.

A significant hurdle to advancing knowledge and training is that geoarchaeology is not a standard component of archaeology degrees in the UK – despite all artefacts and features being integrally linked to the soils and sediments that make up any archaeological site. In the UK, fewer universities are teaching geoarchaeology at undergraduate or taught postgraduate level today than 20 years ago. However, a wide range of computer software now exists that can ostensibly create deposit models, and therefore if we have the software do we need the geoarchaeological expertise? This is a pressing question as workshop delegates were concerned that there was not always a deposit modeller available to undertake the work when required. It could be argued that there is little sense in promoting the use of deposit models if the skills and capacity to produce them does not exist.

First-hand experience of workshop delegates suggested that recruitment of new staff with appropriate geoarchaeological skills was difficult, which partly reflected the lack of university training. However, it was also suggested that the skill-set and experience needed to work as a geoarchaeologist on developer-funded projects is quite specific and is possibly best taught ‘on the job’ if the candidate has the right background. Anecdotal evidence with respect to several jobs recently advertised (mid 2016) indicated that there had been few applicants and typically those who applied lacked suitable experience and skills. Higher research degrees in allied disciplines of earth sciences or related subjects, for example, palaeoecology, geophysics or GIS, do not offset a lack of work experience in commercial archaeology; and experienced field archaeologists with no knowledge of soils, sediments or Quaternary chronology would need significant training. A further challenge in recruiting geoarchaeologists is that opportunities for career progression are limited and specialists tend to earn less than project managers and consultants. Hence incentives for experienced geoarchaeologists to work as specialists are not great and most have to move sideways into more administrative and management roles to develop their careers. However, the shortage of skilled staff, or indeed the issue of pay and career progression, are certainly not unique to geoarchaeology, but it does suggest that if universities who are responsible for supplying undergraduate and postgraduate students with appropriate skill-sets are failing to do so, then the profession needs to consider how this skills shortage might be addressed.

Several potential avenues for increasing capacity in geoarchaeology and specifically deposit modelling were suggested during the break-out sessions. Firstly, taking opportunities to develop understanding of landscape processes, sediments and soils amongst field-staff might encourage a geoarchaeological perspective in standard archaeological approaches. Archaeologists who are already thinking along geoarchaeological lines are more likely to be receptive to deposit modelling techniques. Training might also be provided by: toolbox talks on appropriate sites; geoarchaeologists regularly working alongside the excavators; and more formal sessions, either provided internally by archaeological units or under the auspices of CIfA and Historic England. Secondly, involving archaeologists in the capture of geotechnical data and inputting stages of deposit modelling has worked on a number of projects and provides archaeologists with insights into the methodological process. In urban contexts, in particular, information on stratigraphic sequences at discrete locations is often extracted from archaeological records; this data collection could reasonably be done by archaeologists under appropriate guidance. Data inputting might also be done by non-specialists, especially if basic information and supervision is provided (such as marked-up sediment logs). However, there are always concerns when using non specialists for specialist tasks, especially when this is done for commercial reasons. In practical terms too, defining which data is input and how it is characterised, as well as interpreting the results, must be done by somebody familiar with the deposits being modelled; this is almost always likely to be a geoarchaeologist.

Simple deposit models, placing the sediment sequence and characteristics seen in a section face or borehole into a wider context by comparison with other exposures, landforms and geology, lie at the heart of geoarchaeology. Like the archaeologist considering the characteristics of made ground across a site, however, this basic approach to understanding deposits is hardly thought of as a deposit model. Most deposit models are based on large datasets, which require the use of computer software to handle, manipulate and understand the distribution of deposits. In many cases the experts in the software (Rockworks, ArcGIS) are not the geoarchaeologists themselves and many geoarchaeologists are not overly skilled in using such software, preferring to work on paper in the first instance. However, if significant datasets are involved and software is needed, the geoarchaeologist is at a disadvantage if they cannot use modelling software to gain maximum benefit from the data.

The models presented at the workshop and illustrated as individual chapters within this volume are by their very nature aimed to be relatively simple in order to demystify the subject of deposit modelling. As the complexity of models increases, so invariably do the skills required and knowledge of soils, sediments and landscape processes that lie at the heart of geoarchaeology. Suffice to say that for the moment it is enough to concentrate on getting deposit modelling accepted as a standard archaeological process; in order to do this, the products of every deposit model must be understood by the non-specialists who want to know the archaeological relevance of the results. Therefore, a lack of archaeological awareness on the side of the modeller can undermine the value of a deposit model. For the moment at least, understanding the deposits and making their character and distribution across a site (and in the context of the wider landscape) archaeologically relevant and clear is the essential skill of an archaeological deposit modeller. Unless results are set out very clearly, simply and visually with strong links to archaeological significance, the deposit model is likely to be ignored by the potential end-user. This is damaging to the sector's perception of deposit modelling, as unintelligible work produced by one modeller can have negative repercussions for archaeological deposit modelling more widely. On the other hand, a model that clearly and simply addresses the archaeological questions in a way that can be understood with no technical knowledge required on the part of the end-user will go a long way to encourage the standard use of deposit modelling as an archaeological technique. Therefore, training and skills are an essential pre-requisite of any discussion.

18.4. Break-out Theme 3: minimum standards and outputs

To discuss the minimum standards required by a deposit model, in the first instance a general consensus must be achieved regarding what a deposit model is and what the deposit model is used for. Whilst an obvious statement is deposit models investigate subsurface stratigraphy, how they actually do this and what results are generated from these investigations is much more variable.

During roundtable discussions there was general agreement that a deposit model was constructed from 'more than one borehole', as this requires interpolation between data points to understand the nature of and interpret subsurface stratigraphy. It was also considered that a deposit model must make a statement of 'archaeological potential' and be used for managing archaeological risk within the planning process.

It was also noted that a variety of terms are used to describe deposit models: for example, predictive models, geoarchaeological potential models and geological models, with each term having a slightly different meaning, dependent on the user group. Going forward, there is a need to standardize terminology and practices relating to this subject.

A range of views were presented as to what could and should be expected from a deposit model. It was felt generally that both the inputs to, and outputs from, deposit models were rarely specified, and that this reflected limited use by curators and other planning archaeologists. Often, there is the sense that it is the contractors who suggest the provision of a deposit model to aid site understanding, and therefore the outputs and standards are shaped by the specialist rather than the curatorial/planning archaeologist who may lack the knowledge and confidence to specify deposit models during the drafting of archaeological briefs. This creates an interesting driver to deposit modelling within the UK and also raises significant questions regarding what are essential data inputs and outputs given the competitive nature of tendering and the need for organisations to invariably 'cut their cloth' to secure work. If care is not taken, this could lead to a 'colouring by numbers' approach to deposit modelling rather than tailoring both the inputs and outputs to the specific requirements of any given project.

In the context of roundtable discussions, a number of minimum outputs were suggested. All deposit models should identify significant sedimentary units, model 'key' upper and/or lower bounding surfaces, and reconstruct at least one representative cross-section. An accompanying report must include a description of the inputted data, the precise method of model construction (software, interpolation functions etc), a consideration of archaeological risk, a statement of archaeological potential and a non-technical summary.

Deposit modellers must also be explicit about the level of confidence that can be placed on individual models and the data used to construct it; where there are concerns with respect to the integrity of data, these should be clearly expressed. For example, when using geophysical data, such as that collected through electrical resistivity survey, the interface between sediment units is interpreted in two stages. Firstly, the proxy data such as the resistivity values are measured and interpreted; secondly, these values are used to identify variations in sediment structure and texture, which are related back to formation process and environment of deposition. The interpreted geophysical dataset can then be compared with borehole data where changes in sediment type are logged directly. This difference in using data to achieve the same end point (ie the interpretation of a sedimentary sequence) needs to be clearly identified in a deposit modellers' report. This openness is essential so that secondary users of deposit models do not misinterpret outputs and in so doing, make unsound archaeological inferences from the model.

As a general rule, it was considered that geophysical data should not be used in isolation and for deposit modelling, it must always be supplemented by ground-truthing from borehole data or hand augering to securely interpret trends in the geophysical data. Any primary geotechnical data used for constructing a deposit model should also form an appendix to the associated report, although it is recognised that issues of confidentiality may come into play here, especially if deposit models are to be archived with a HER and/or the ADS.

Therefore, deposit models must contain a clear distinction between data and interpretation, and as well as clear definition of the data, there also needs to be a clear definition of what is being interpreted from the data. Is the deposit model seeking to define archaeological contexts, sedimentary units, broader depositional environments, palaeolandsurfaces, or all of the above? Each of these terms requires definition and clarity when used by deposit modellers, especially when they are translated for the end-users, who might include the field archaeologist, the curator and/or the developer. A further standardisation that should be applied to each deposit model is a clear definition of what the key sediment units are and why they are important. Further statements should accompany this on the difference (or similarity) between key sediment units and distinct archaeological contexts.

With regards to what is being interpreted and inferred from the deposit models, a clear distinction was emphasised between archaeological potential and preservation potential, with this theme picked up, for example, in the individual chapters of both Malim (Chapter 15) and Hunter-Mann and Oxley (Chapter 16). Advanced deposit models can capture data relating to groundwater and geochemical conditions (eg perched watertables, redox, pH etc) that can aid assessment of archaeological potential and survival.

18.4.1. Baseline information and data sources

The question of what actually constitute baseline data and techniques for deposit modelling provided fluid debate but ended with little clarification of the issues due to the variable nature of deposit modelling and the fact that each model is unique. Nearly all deposit models will consult pre-existing geotechnical data and this is considered a key requirement. However, accessing previously collected geotechnical data for individual sites is far from straightforward, especially if confidential. It was considered that the commissioning of purposive boreholes was desirable, but this was not always practical, especially if budgets are limited. Using general geotechnical records have the added problem that when described by geotechnical engineers, they lack sufficient descriptive detail for geoarchaeologists; for example, the term 'made ground' can cover a variety of deposit types but also include archaeologically-significant sediments, including structures.

18.4.2. How can deposit models be presented more clearly?

Deposit models are usually produced in colour format and many colour schemes used are intuitive; for example, rivers or potential palaeochannels shaded in blue, organic areas depicted by black. To provide extra clarity, deposit models should include additional information that allows the end-user to orientate themselves, for example, in relation to local landmarks, Ordnance Survey maps and field numbers. Time invested in producing high-quality graphics and tools for visualisation was considered as being a priority to help explain deposit model outputs. Two-dimensional topographic surfaces and cross-sections were considered essential outputs from deposit models with three-dimensional rotational visualisations seen as desirable. Whilst illustrations might be complex in terms of what they convey, they must be interpretable by a more generalised readership and where annotated, they must be free of jargon. This is critical since the data does not speak for itself and it is important that the specialist guides the generalist through the relevance of the outputs.

Once created, deposit models should be more closely integrated with the ground-truthing of the archaeological remains, gleaned through the process of evaluation and excavation. Part of this process, tying together the recovery of archaeology and the initial deposit model, will have to occur as part of a post-excavation process, but beginning this process early on was considered a valuable step in assessing how successful a deposit model has been in identifying archaeology.

However, what this testing would consist of was not agreed on, ranging from qualitative assessments through to the use of statistics. From both a modellers' and curatorial perspective if deposit models are going to be prescribed as part of the development process, confidence has to be demonstrated in the modelling process. As well as reflecting on the usefulness of deposit models on individual sites, it was also considered desirable that some models are compared using different data sources, different software and by different groups to compare outputs when the archaeological reality of a location was known. Such tests need to be disseminated to the wider deposit modelling community with clarity of the level of success as well as the limitations of models. It was considered worthwhile to provide future forums to discuss the success and failures of deposit models against emergent archaeological realities. There was an acknowledgement of the low level of publication of deposit models in general, and very few that compare the results of deposit models to subsequent excavation data.

18.5. Break-out Theme 4: archives and long-term data-management

The final break-out identified a number of key themes.

18.5.1. Archive contents

There was extensive discussion on the subject of the geoarchaeological, locational and other data that should be incorporated in project archives and the format of these data. It was emphasised that although the derived models provided important insights into landscape development and anthropogenic impact, the key priority was the preservation of primary data in robust formats that could be accessed easily by future researchers. Only if this were achieved, it was argued, would it be possible for future workers to review and reinterpret the data upon which models had been developed and to test the conclusions that had been drawn previously.

To achieve this result, it was recommended that Written Schemes of Investigation in advance of development include the requirement that contractors submit the primary data, derived model and report to an accredited archive. This guidance would empower the curator to insist upon the definition of an archive strategy at the outset of deposit modelling projects and thus expedite storage in an appropriate format of the primary data acquired during field investigations. It was argued that this requirement should be extended to University-based and other researchers conducting ground investigations outside of the development process, including community groups engaged in geoarchaeological investigations (as at Farndon Fields, Nottinghamshire: Garton *et al* 2015).

18.5.2. Archive stores and data formats

It was recommended that an accredited digital archive such as that maintained by the British Geological Survey or the Archaeology Data Service should be identified for data generated during the deposit modelling process. It was proposed that digital data should also be integrated with the appropriate regional Historic Environment Record. It is therefore critical that investigators liaise on GIS and other software packages with Historic Environment Records (HER) staff at the project development stage. This, it was felt, would enable the effective integration of project data into the HER and would assist the development of programmes of investigation and analysis that addressed directly regional research and management priorities.

To ensure maximum access to preserved archives, it was recommended that digital data be stored in simple formats that would ensure accessibility to future researchers (eg as csv files). The advantages of ensuring deposition of paper as well as scanned records of documentary archive material (relating for example to borehole descriptions) were also emphasised, although it was recognised that the feasibility of this would depend upon the availability of adequate storage space in an appropriate regional museum.

18.5.3. Evolution of deposit models

It was recommended that investigators consult wherever possible the results of previous exercises of deposit modelling on or close to the study area, as this would permit the development of more targeted and cost-effective investigation strategies. It was felt that knowledge of data acquired during earlier investigations on or close to the site would also facilitate interpretation of results gained during borehole surveys and other ground investigations. Plotting of palaeochannel deposits within proposed quarry extraction zones, for example, would be expedited if these could be assessed within wider interpretative frameworks such as that developed for the Trent catchment (Baker 2006; Stein *et al* 2017).

It was recommended that reports on work conducted should include a review of previous deposit models developed within or close to the study area. This would provide the opportunity to consider how the most recent phase of investigations has enhanced or challenged established deposit models, thereby enhancing understanding of regional landscape development.

18.5.4. Integration of results of multiple projects

It was noted that several recently completed ‘Big Data’ projects, such as that focused upon archaeological investigations in advance of aggregates extraction in the Upper Thames (Morrison *et al* 2014), had flagged the problems of interpreting landscape change on the basis of multiple interventions by different contractors over protracted time periods. It was recognised that problems of software compatibility may complicate attempts to integrate multiple surveys. However, modes of achieving this should be considered during the project development stage in liaison with the regional historic environment curator, and deposit modellers should be encouraged to share their data in the interest of developing a wider understanding of the landscape.

It was recognised that the integration of past datasets in intensively studied areas such as the Thames or Trent Valleys would be well beyond the scope of developer-funded investigations. For that reason, it was recommended that priority be given to the development of initiatives outside the development process that might facilitate the integration of current datasets. This would release the untapped potential of the data accumulated during past developer-funded investigations, as well as providing a firmer foundation for the development of subsequent schemes of investigation.

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19. Concluding remarks

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By way of a series of technical case studies and overview chapters, this volume has sought to describe how deposit modelling can be used to investigate archaeological sites and landscapes in a wide variety of environments, from terrestrial to perimarine, urban to rural. The selected case studies described herein aim to provide examples of good practice and are underpinned by detailed technical information that considers: the *raison d'être* for modelling; the data and methodologies used; as well as approaches to project archiving and data storage.

By using a largely standardized template, it is intended that the user of this volume, with relative ease, can compare and contrast the approaches taken to deposit modelling and assess the additional information and therefore insights that it can deliver for archaeological projects. Whilst the case studies outlined here are considered examples of good practice, it must be stressed that the methodologies described are not considered fixed or rigid, and no one approach will provide a 'one fits all' solution for a particular environment or site type. Rather, with a range of knowledge to hand, the user may tailor methodologies for their site, perhaps mixing and matching a number of technical elements described here.

It must be emphasised that deposit modelling as a sub-discipline of geoarchaeology is still very much in its infancy. Chapter 18 has been written largely on the basis of thoughts and opinions captured during a workshop of practitioners and stakeholders held in London (June 2016), prior to the editing of this volume. The chapter demonstrates that there are still many issues to be considered and challenges to be overcome, especially with respect to data standards, archiving, training and skills capacity. This volume does not claim to provide solutions to many of the issues discussed; however, it is hoped that it goes some considerable way to advancing common themes and goals, and will provide a foundational platform for further discussion and methodological development.

Perhaps most importantly of all, together with the Historic England Guidance Document *Deposit Modelling for Archaeological Projects* that is currently in preparation, it is hoped that this volume will provide a wide-ranging group of heritage practitioners, not just geoarchaeologists and environmental archaeologists, with the knowledge and therefore confidence to use deposit modelling as part of the wider tool-kit for archaeological investigation.

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