Immingham Green Energy Terminal

9.85 Updated Peat Analysis Information

Infrastructure Planning (Examination Procedure) Rules 2010

Volume 9

July 2024

Planning Inspectorate Scheme Ref: TR030008

Document Reference: TR030008/EXAM/9.85

Table of contents

Introduction

Overview

1.1 This document has been prepared to accompany an application made to the Secretary of State for Transport (the Application") under section 37 of the Planning Act 2008 ("PA 2008") for a development consent order ("DCO") to authorise the construction and operation of the proposed Immingham Green Energy Terminal ("the Project").

1.2 The Application is submitted by Associated British Ports ("the Applicant"). The Applicant was established in 1981 following the privatisation of the British Transport Docks Board. **The Funding Statement [APP-010]** provides further information.

1.3 The Project as proposed by the Applicant falls within the definition of a Nationally Significant Infrastructure Project ("NSIP") as set out in Sections 14(1)(j), 24(2) and 24(3)(c) of the PA 2008.

The Project

1.4 The Applicant is seeking to construct, operate and maintain the Immingham Green Energy Terminal, comprising a new multi-user liquid bulk green energy terminal located on the eastern side of the Port of Immingham (the "Port").

1.5 The Project includes the construction and operation of a green hydrogen production facility, which would be delivered and operated by Air Products (BR) Limited ("Air Products"). Air Products will be the first customer of the new terminal, whereby green ammonia will be imported via the jetty and converted on-site into green hydrogen, making a positive contribution to the UK's net zero agenda by helping to decarbonise the United Kingdom's (UK) industrial activities and in particular the heavy transport sector.

1.6 A detailed description of the Project is included in **Chapter 2: The Project** of the **Environmental Statement ("ES") [REP3-022]**.

Purpose and Structure of this Document

1.7 The purpose of this document is to provide updated peat analysis information, covering how different piling methods might impact deposits of high archaeological potential. This information was discussed by the Examining Authority at Issue Specific Hearing 8 on July 2 2024, but not formally requested in the **Action Points from Issue Specific Hearing 8 [EV11-001]**, issued July 5 2024.

1. Updated Peat Analysis Information

Updated peat analysis information, covering how different piling methods might impact deposits of high archaeological potential
Environmental Statement ("ES") Chapter 14: Historical Environment (Terrestrial) [APP-056], **Paragraph 14.9.3**, outlines that a meeting on 28 of July 2023 with the Heritage Officer for North East Lincolnshire Council ("NELC") resulted in the following decisions being made with regards to whether further archaeological work was required in relation to the Project (the decisions are summarised below): a) West Site – Archaeology. No further archaeological work was required at this location. b) West Site – Geoarchaeology. The evaluation suggested that the retained borehole samples of peat and organic alluvium had palaeoenvironmental potential. It was agreed that, rather than conducting additional fieldwork, the samples retained be subject to further analytical work, and a report detailing the results of this work be prepared and submitted to AECOM who would review and then disseminate the report to the Applicant and the Heritage Officer for NELC for their review and approval (as included within the **Outline Construction Environmental Management Plan ("CEMP") [AS-043]**). No further field work was required. c) Pipeline Corridor. No further archaeological work was required. d) East Site. No further archaeological work was required. e) Temporary Construction Area. No further archaeological work was required as the potential remains will be preserved *in situ*. The further analytical work on the peat cores and samples, recovered from boreholes drilled during a geoarchaeological borehole survey, has been completed. The assessment is presented in the palaeoenvironmental assessment report at **Appendix 1** and was written by Wessex Archaeology. This followed an initial geoarchaeological borehole survey and deposit modelling, reported in **ES Appendix 14.G: Report on Geoarchaeological Survey and monitoring of Geotechnical Investigations [APP-201]**, which recorded a sequence of Pleistocene glacial till, overlain by localised Holocene peat deposits and more widespread alluvium across the Site. The peat deposits were formed during the mid-Holocene, within reed swamps or sedge fen in localised backwaters or abandoned channels within a saltmarsh environment, likely with alder carr woodland on the wider floodplain. The peat deposits have been radiocarbon dated to the Late Mesolithic period. The peat deposits are overlain by thick deposits of estuarine organic alluvium, again likely forming under saltmarsh conditions, or formed by the reworking (erosion and deposition) of organic sediments and peats from the wider floodplain into an alluvial sequence. The alluvial deposits are also radiocarbon dated to the Late Mesolithic period.

The further assessment considered evidence within the sequences for pollen, diatoms, foraminifera, ostracods and plant macroremains. On the basis of their preservation and concentrations, no further analysis of diatoms, ostracods or foraminifera is recommended by the specialists in the report. Also, with regards to the pollen and plant macroremains, no further analysis is recommended, given the age of the peat deposits and lack of any clear associated evidence of human activity with the deposits. The vegetational history of the Late Mesolithic period within the Humber Estuary is well studied, and further analysis of peat samples from the Site is not recommended – as frequent, and often thicker, peat deposits spanning the Late Mesolithic are present elsewhere along the Humber, including sites with evidence of human occupation.

As indicated in **Table 14-7: Summary of Residual Effects**, within **ES Chapter 14**, this further analytical work comprises the additional mitigation measures for impacts to the peat and alluvial deposits. **Paragraph 14.12.5** states that this will mitigate against direct impact of the Project on these underlying deposits. As explained above, this analysis has now been completed and no further work on the peat or alluvium samples is recommended. Also as outlined above, no further archaeological field work on the peat or alluvial deposits is required, following agreement with the Heritage Officer for NELC. In summary, therefore, no further archaeological assessment will be required, subject to confirmation of the adequacy of the appended palaeoenvironmental assessment report. The Heritage Officer for NELC has accepted the appended palaeoenvironmental assessment report in an email to AECOM on 9 July 2024 and the recommendation that no further work be undertaken on the peat and organic alluvium deposits.

The palaeoenvironmental assessment report does not impact the conclusions of **ES Chapter 14 [APP-056]** in relation to likely significant effects and has no bearing on the approach to be taken to piling, as the deposits do not require any further archaeological work / sampling – they are signed-off for construction. The palaeoenvironmental assessment report, which has been lodged with the Heritage Officer for NELC, constitutes the mitigation for the impacts of any form of piling on the peat deposits, much of which will be retained *in situ*, beneath the development. The **Outline CEMP** has been updated for Deadline 5 **[TR030008/APP/6.5 (6)]** to reflect that the palaeoenvironmental assessment report has been completed.

2. Appendix to the Updated Peat Analysis Information

NH Immingham Palaeoenvironmental Assessment Report

NH3 Immingham

Palaeoenvironmental Assessment

Document Ref.: 27004.02
June 2024

wessexarchaeology

Portway House
Old Sarum Park
Salisbury
SP4 6EB

www.wessexarch.co.uk

Document Information

Document title	NH3 Immingham Green Energy Terminal
Document subtitle	Palaeoenvironmental Assessment Report
Document reference	271004.01
Client name	AECOM Ltd (Leeds)
Address	5th Floor 2 City Walk Leeds LS11 9AR
Site location	Land off Kings Road Immingham North Lincolnshire DN40 1QT
County	Lincolnshire
National grid reference	NGR 519890, 414605 (TA 19890 14605)
Planning authority	North East Lincolnshire Council
OASIS ID	wessexar1-525353
WA project name	NH3 Immingham Palaeoenvironmental Assessment
WA project code	271004
Project management by	Dr Alexander Brown
Document compiled by	Dr Jack Oughton and Dr Daniel Young
Contributions from	Dr John Athersuch (foraminifera/ostracods), Dr Nigel Cameron (diatoms), Dr Inés Lópex-Dóriga (radiocarbon dating), Megan Scantlebury (plant macroremains) and Dr Jack Oughton (pollen)
Graphics by	Kitty Foster

Quality Assurance

Issue number & date		Status	Author	Approved by
1	20/05/2024	Draft	JWO [redacted]	[redacted]
2	11/06/2024	v2	JWO	ADB

Contents

List of Figures

List of Tables

Summary

Wessex Archaeology was commissioned by AECOM to produce a report on the palaeoenvironmental assessment of boreholes recovered during a geoarchaeological borehole survey at NH3 Immingham Green Energy Terminal, Immingham, North Lincolnshire. This report follows on from the results of the geoarchaeological borehole survey and deposit modelling, which recorded a sequence of Pleistocene glacial till, overlain by localised Holocene peat deposits, and more widespread organic alluvium and minerogenic alluvium.

The peat and organic alluvium were highlighted as having high palaeoenvironmental potential, with targeted recommendations made for palaeoenvironmental assessment and radiocarbon dating. The principal aim of this report is to determine the age, nature and depositional history of the deposits recovered at the site, as well as the preservation potential of the palaeoenvironmental remains and their potential for further analysis.

The peat deposits at the Site formed during the mid-Holocene, within reed swamp or sedge fen environments, forming in response to background sea-level rise. Radiocarbon dates of peat deposits from three boreholes have produced dates placing peat formation in the Late Mesolithic. Given the localised nature of the peat, these sediments may have accumulated in localised backwaters or abandoned channels within a wider saltmarsh environment. The combined results of the palaeoenvironmental assessment are consistent with a sedge fen or reed swamp environment associated with the peat deposits, likely with areas of alder carr woodland on the wider floodplain. The dryland environment during the accumulation of the peat was dominated by mixed deciduous woodland, dominated by oak, lime and hazel, consistent with a mid-Holocene date for the deposits. No clear evidence for human activity was identified within the peat.

The thick sequences of estuarine alluvium overlying the peat can be correlated with widespread alluviation in the wider Humber Estuary. The estuarine alluvium includes organic alluvium that is in places up to c. 5 m thick, likely forming in salt marsh and/or reflecting the reworking (erosion and deposition) of organic sediments and peat from the wider floodplain into the alluvial sequence. Radiocarbon dating of the organic alluvium yielded dates of the Late Mesolithic period, although the basal date is an outlier.

The results of the palaeoenvironmental assessment of the organic alluvium are consistent with salt marsh environments, with the pollen dominated by goosefoot family, grasses, and sedges, with a dryland vegetation of mixed deciduous woodland similar to that recorded in the peat. The diatom assemblage was indicative of brackish marine conditions. The foraminifera and ostracod assemblage were indicative of estuarine conditions, and contained frequent reworked microfossil remains. No clear evidence for human activity was identified within the organic alluvium, although low concentrations of microcharcoal of uncertain origin (i.e., natural or anthropogenic) were present in various samples.

On the basis of their preservation and concentrations, no further analysis of diatoms, ostracods or foraminifera is recommended. No further analysis of pollen or plant macroremains is recommended, given the age of the peat deposits and lack of any clear evidence of human activity within the pollen record. The vegetational history of the Late Mesolithic of the Humber is well studied, and further analysis of peat samples from the Site is unlikely to provide further information on the geoarchaeological and archaeological resource available.

Acknowledgements

Wessex Archaeology would like to thank AECOM for commissioning the work included in the report, in particular to Helen Kelleher. The report was written by Dr Jack Oughton and Dr Daniel Young, with contributions from Dr John Athersuch, Dr Nigel Cameron, Dr Inés López-Dóriga and Megan Scantlebury. The report was edited by Dr Daniel Young. Figures were produced by Kitty Foster. The project was managed by Dr Alex Brown on behalf of Wessex Archaeology.

NH3 Immingham

Palaeoenvironmental Assessment

1 INTRODUCTION

1.1 Project and planning background

1.1.1 Wessex Archaeology was commissioned by AECOM ('the Client') to undertake a palaeoenvironmental assessment of samples taken during a geoarchaeological borehole survey at NH3 Immingham Green Energy Terminal, Immingham, North Lincolnshire ('the Site'). This Site is centred on National Grid Reference 519780, 414720 (TA 19780 14720) (**Figure 1**).

1.1.2 The proposed development comprises an ammonia import terminal forming part of the proposed Green Energy Terminal at Immingham. The geoarchaeological borehole survey was focused on the West Site and Pipeline Corridor, with the geotechnical watching brief focusing on the West Site, Pipeline Corridor and East Site.

1.1.3 The program of geoarchaeological works was designed to provide information on the geoarchaeological and archaeological resource likely to be impacted by the proposed development to facilitate an informed decision with regard to any further archaeological and geoarchaeological work that may be required; or the formation of a mitigation strategy or a management strategy.

1.1.4 During the geoarchaeological borehole survey (Wessex Archaeology 2023), superficial geological deposits with high palaeoenvironmental potential were identified, from which core samples for palaeoenvironmental assessment were retained.

1.1.5 The palaeoenvironmental assessment will provide further information on the archaeological resource that may be impacted by the proposed development and facilitate an informed decision with regard to the requirement for, and methods of, any further work that may be required. This work may include analysis of the material assessed and/or further targeted sampling as part of archaeological and geoarchaeological mitigation.

1.2 Scope of document

1.2.1 Quaternary superficial sediments of Pleistocene and Holocene date may have the potential to contain environmental remains reflective of past human activity, landscapes, and environments. Palaeoenvironmental assessment is therefore part of a staged approach to assessing the archaeological potential of Quaternary deposits.

1.2.2 The staged approach to such investigations developed by Wessex Archaeology comprises four-stages, each encompassing different levels of investigation appropriate to the results obtained, accompanied by formal reporting of the results at the level achieved. The stages are summarised below (**Table 1**). This report represents Stage 3 of this process.

Table 1 Staged approach to geoarchaeological investigations

Stage 1: Geoarchaeological Desk-based Assessment (GDBA) and deposit modelling	A geoarchaeological desk-based assessment (DBA) examines a range of information (published and unpublished ("grey literature"), LiDAR, historic maps) and models existing Ground Investigation (GI) data to inform on the possible archaeological potential of Quaternary deposits within an assessment area. The GDBA may include a Geoarchaeological Landscape Characterisation (GLC) which divides an assessment area into different zones (Geoarchaeological Characterization Zones – GCZs) based on variations in deposits and potential. The GDBA establishes the requirements for and scope of Stage 2 archaeological field evaluation. Should Stage 2 evaluation be required, appropriate and proportionate recommendations for each GCZ are provided.
Stage 2: Archaeological evaluation	Field evaluation to establish the archaeological potential of Quaternary deposits within an evaluation area, which informs on the requirements and scope of Stage 3 palaeoenvironmental assessment and/or Stage 4 mitigation. The principal methods of archaeological evaluation of Quaternary deposits are through targeted machine-dug trenches, test pits and boreholes. An archaeological evaluation report is produced, which includes updated deposit modelling and an updated GLC. If required, recommendations for Stage 3 sample assessment and/or Stage 4 mitigation are made.
Stage 3: Sample assessment	Palaeoenvironmental samples and/or sediment samples recovered during Stage 2 are assessed to inform on the archaeological potential of deposits and guide the scope and need for Stage 4 mitigation. Dating of samples taken during Stage 2 may be required to inform on the archaeological potential of deposits and to guide the scope and need for Stage 4 mitigation. If this is the case, dating will be carried out at this stage. Alternatively dating samples will be retained for Stage 4 mitigation, if required. Recommendations for dating requirements during Stage 3 are made in the Stage 2 report. A sample assessment report is produced outlining the palaeoenvironmental and dating potential of the deposits including targeted and proportionate recommendations for Stage 4 mitigation.
Stage 4: Archaeological mitigation	Based on the results of the Stage 2 and 3 investigations archaeological mitigation may be required to offset development impacts. Mitigation may include archaeological excavation, targeted geoarchaeological sampling for paleoenvironmental analysis and dating and artefact analysis. A final mitigation report is provided on completion of mitigation program.
Publication	The scope and location of a publication report will be agreed in consultation with the client and LPA advisor. The publication report may comprise a note in a local journal or a larger publication article or monograph, dependant on the significance of the archaeological work.

1.2.3 This Palaeoenvironmental Assessment considers the potential of sediments sampled during the Stage 2 to preserve significant palaeoenvironmental datasets. The results will inform any requirements for and scope of further work, which may include Stage 4 analysis, or targeted sampling as part of archaeological mitigation.

1.2.4 In format and content, it conforms to current best practice, as well as to the guidance in *Management of Research Projects in the Historic Environment* (MoRPHE, Historic England

[HE] 2015) and *Environmental Archaeology. A Guide to the Theory and Practice of Methods, from Sampling and Recovery to Post-excavation* (English Heritage [EH] 2011).

2 PROJECT BACKGROUND

2.1 Introduction

2.1.1 The section provides background information on the Quaternary deposits from which the assessed samples were recovered. The samples subject to this assessment were obtained from peat and organic alluvium in boreholes recovered during the geoarchaeological borehole survey (Wessex Archaeology 2023; **Figure 1**).

2.2 Quaternary deposits and archaeological context

2.2.1 Wessex Archaeology (2023) identified a lithostratigraphy associated with the assessed samples comprising:

- Glacial Till (Pleistocene)
- Peat (Holocene)
- Organic Alluvium (Holocene)
- Minerogenic Alluvium (Alluvium)
- Topsoil (Recent)

2.2.2 The solid geology, as mapped by the British Geological Society (BGS), is Burnham Chalk Formation. This is chalk deposits which formed between 93.9 to 83.6 million years ago (Mya) during the Cretaceous period (BGS GeoIndex). Detailed background information on the Quaternary deposits and their archaeological context is provided in a Stage 2 evaluation report (Wessex Archaeology 2023). Summary information relevant to the assessment is provided below.

Glacial Till (Pleistocene)

2.2.3 Glacial till deposits, typically comprised of sandy silts, silty clays and clays with frequent gravel clasts were recorded overlying the chalk bedrock across the Site. This unit was typically greater than 10m thick, with an average thickness of c.12 m. The upper surface elevation varied across the Site, from c.-4 m OD in the west and c.-8 m OD in the east.

2.2.4 These deposits would likely have been deposited by the advancing Late Devensian ice sheet, which reached its maximum extent in the area during the Last Glacial Maximum between 23 and 17 Kya.

Minerogenic Alluvium (Holocene)

2.2.5 Minerogenic alluvium deposits, described as sandy or slightly gravelly silty clay were recorded overlying the glacial till across the Site. The upper surface elevation varied across the Site, between 1 – 2 m OD across the majority of the Site, and between 3 – 4 m OD in the east of the Site.

2.2.6 These deposits would have formed during the influence of rising sea levels during the Holocene, with formation occurring in association with the early Holocene channel systems, and later mudflat and saltmarsh environments associated with the intertidal floodplains of the Humber Estuary.

Peat (Holocene)

2.2.7 Peat deposits, described as firm to soft, black, richly organic laminated silts, were present locally across the Site, overlying glacial till deposits. Peat deposits were local in the west and the Pipeline Corridor, and largely absent from the east of the Site. The thickness of the peat varies from 0.08 – 1.15 m thick, and the upper surface elevation ranges from -5.5 - -8.0 m OD.

2.2.8 Peat deposits form in semi-terrestrial conditions, associated with the growth of wetland vegetation such as that observed in reed swamps, sedge fens and alder carr, typically as a response to a reduction in the rate of relative sea level rise. The distribution of peat at the Site is indicative of peat formation in floodplain hollows or within a network of dendritic channels, typical of those that grow in mudflats.

Organic Alluvium (Holocene)

2.2.9 Organic alluvium deposits, described as firm to soft, black to dark grey laminated silts with frequent organic material and mollusc shell, are present across much of the Site, but more localised in the east of the Site. Organic alluvium deposits are present at various elevations within the Holocene alluvial sequence, occurring from -8.0 m - 1.5 m OD.

2.2.10 These deposits would likely have formed in low energy environments, such as slow-moving or deactivated channels in freshwater backswamp or more vegetated saltmarsh environments.

2.3 Sampling and assessment strategy

2.3.1 Sampling was undertaken from three purposive geoarchaeological borehole (BH13, BH14 and BH17) and from a single GI borehole (W-BH35). These samples targeted the organic alluvium and peat deposits recorded within the boreholes, and included pollen, foraminifera/ostracods, diatoms and plant macroremains.

2.3.2 Plant macroremains samples were taken from the top and the base of peat deposits (BH13, BH14), and the top and the base of the organic alluvium (BH17). Only a single plant macroremains sample was taken for assessment from W-BH35. Following the assessment of plant macroremains, suitable material would be selected for radiocarbon dating. Given the position of the samples from the deposits, this would provide dates for the onset and conclusion of peat formation.

2.3.3 Pollen samples were taken across the organic alluvium (BH17) and peat (BH13, BH14 and BH17) deposits. These were taken at regular intervals throughout the deposits, and would provide information on vegetational history throughout the sequence.

2.3.4 Diatoms and foraminifera/ostracod samples were taken from organic alluvium deposits (BH13, BH14 and BH17). They were taken at regular intervals throughout the deposits and provide information on palaeoenvironmental conditions, such as salinity.

3 AIMS AND OBJECTIVES

3.1.1 The principal aims of the Stage 3 Palaeoenvironmental Assessment were to:

- determine the nature, depositional history and approximate age of selected deposits;
- determine the preservation potential and concentration of palaeoenvironmental remains within selected deposits;

- interpret the results to inform reconstructions of past environmental and landscape change (e.g. vegetation and sea level), and
- assess geoarchaeological (paleoenvironmental) potential of selected deposits.

3.1.2 These aims were addressed by achieving the following objectives:

- To provide an age framework for the organic alluvium and peat deposition at the Site, via the use of radiocarbon dating;
- Provide data on the vegetational, climate and sea level history of the Site, via the use of pollen, plant macroremains, diatoms, ostracod and foraminifera proxies.

4 METHODS

4.1 Introduction

4.1.1 A total of 70 samples from four interventions were selected for assessment (see **Table 2** and a full list in **Appendix 1**). The samples subject to this assessment were obtained from peat and organic alluvium in boreholes recovered during the geoarchaeological borehole survey (Wessex Archaeology 2023; **Figure 2**), namely from the following boreholes:

- BH13, BH14 and W-BH35 (from the 'Central' transect);
- BH17 (from the 'East' transect).

4.1.1 Recommendations for Stage 3 Palaeoenvironmental Assessment were made in the Stage 2 report (Wessex Archaeology 2023). These recommendations are summarised in **Table 2**.

Table 2 Scope of the Stage 3 palaeoenvironmental assessment

Borehole	Deposit	Number of samples			
		Pollen	Foraminifera / Ostracod	Diatoms	Plant macro-remains/ radiocarbon dating
BH13	Organic Alluvium		2	2	
BH13	Peat	5			2
BH14	Organic Alluvium		2	2	
BH14	Peat	5			2
BH17	Organic Alluvium	13	15	15	2
BH17	Peat	2			
W-BH35	Peat				1

4.2 Radiocarbon dating

4.2.1 Plant macrofossils extracted from the sediment sub-samples from BH13 (two sub-samples), BH14 (two sub-samples), BH17 (two sub-samples) and W-BH35 (one sub-sample) were submitted for radiocarbon dating with the aim of obtaining a chronological framework for the formation of peat and organic alluvium deposits (**Figure 4**).

4.2.2 Where possible, single-entity, short-lived samples of waterlogged plant remains (e.g., fruits, leaves) and wood (e.g., twigs) were selected for radiocarbon dating following Historic England's guidelines for Radiocarbon Dating and Chronological Modelling (Bayliss and Marshall 2022). Sample selection was undertaken by the project specialists (Megan Scantlebury and Ed Treasure) and was constrained by the availability of suitable short-lived secure material.

4.2.3 Extracted remains were stored in a small quantity of de-ionised water in glassware and refrigerated prior to submission. The samples were submitted for radiocarbon dating to the ^{14}Chrono Centre, Queen's University Belfast. The samples were pre-treated and measured following standard procedures (^{14}Chrono 2019).

4.2.4 The calendar age ranges were calculated with OxCal 4.4 (Bronk-Ramsey 2009) using the IntCal20 curve (Reimer *et al.* 2020). When multiple dates were obtained from a single sequence, these were modelled in OxCal 4.4 (Bronk-Ramsey 2009) as a sequence with un-uniform deposition rates, with the mm as the unit for the spacing of events and with 1 event per unit length (P_Sequence with 1 as interpolation value and 10 as k variable; Bronk Ramsey 2008, Bronk Ramsey and Lee 2013). Date estimates for particular events (i.e. end of peat formation) were calculated based on their depth in the sequence.

4.2.5 Calibrated date ranges are given at 95% confidence, with the end points rounded out to the nearest 10 years; modelled date ranges (posterior density estimates) are given in italics at 68% confidence, with the end points rounded out to the nearest 5 years.

4.3 Plant macroremains

4.3.1 A total of seven sub-samples from BH13 (two sub-samples), BH14 (two sub-samples), BH17 (two sub-samples) and W-BH35 (one sub-sample) were processed for assessment of plant macroremains.

4.3.2 The subsamples were between 15 to 60 ml in volume, and they were processed by wet sieving using a 63- or 125-micron mesh. After processing, the samples were kept wet and stored in a refrigerated unit prior to assessment. All remains extracted for radiocarbon dating were stored in sealed glass containers with a small volume of de-ionised water and refrigerated to limit any fungal growth or degradation of the material.

4.3.3 The processed samples were rapidly scanned using a stereomicroscope at up to 40x magnification for uncharred and charred botanical remains, including organic/vegetative material, herbaceous epidermal tissues, wood remains, mosses, and plant macroremains ('seeds'), as well as other material (e.g., insects/invertebrates, molluscs, etc.). Plant macroremains were identified through comparison with modern reference material held by Wessex Archaeology and relevant literature (Cappers *et al*. 2006).

4.3.4 Selected wood fragments were identified through examination of the transverse, tangential longitudinal, and radial longitudinal sections at up to 400x magnification. Wood identifications were undertaken through comparison with Wessex Archaeology's reference collection and relevant literature (Gale and Cutler 2000; Hather 2000; Schweingruber 1990).

Nomenclature follows Stace (1997), with additional habitat information taken from Hill *et al*. (2004) and Stroh *et al*. (2023). Seeds and fruits were classified following Cappers *et al.* (2006).Remains were recorded semi-quantitatively on an abundance scale: C = <5 (‘Trace’), B = 5–10 (‘Rare’), A = 10–30 (‘Occasional’), A* = 30–100 (‘Frequent’), A** = 100–500 (‘Common’), A*** = >500 (‘Abundant’).

4.4 Pollen and non-pollen palynomorphs (NPPs)

4.4.1 A total of 25 sub-samples of 5 ml volume were processed using standard pollen extraction methods (see Branch et al. 2005). Five sub-samples were taken from BH13, five samples from BH14 and 15 samples were taken from BH17.

4.4.2 The palynomorphs were extracted as follows: (1) sampling a recorded volume of sediment; (2) deflocculation of the sample in 1% Sodium pyrophosphate; (3) sieving of the sample to remove coarse mineral and organic fractions (>125µ); (4) removal of finer minerogenic fraction using Sodium polytungstate (specific gravity of 2.0g/cm3); (5) acetolysis; (6) staining with safranin and mounting of the sample in glycerol jelly. Each stage of the procedure was preceded and followed by thorough sample cleaning in filtered distilled water. Quality control was maintained by periodic checking of residues, and assembling sample batches from various depths to test for systematic laboratory effects.

4.4.3 Slides were logged in traverses, using a ‘Leitz laborlux’ binocular transmitted light microscope with a mechanical stage. During assessment stage, four traverses of pollen slides were carried out. Assessments aimed to identify >100 terrestrial pollen grains and also noted non-pollen palynomorphs (including dinoflagellate cysts and reworked palynomorphs) of potential palaeoenvironmental or biostratigraphic significance. Counts were entered into an excel spreadsheet for each borehole. For each slide, a summary was recorded, including description of concentration and preservation, gross assemblage compositions and provisional interpretation (where appropriate).

4.4.4 At assessment stage the results are not presented as pollen diagrams but are presented in tabular form as raw data (**Appendix 2**).

4.5 Diatoms

4.5.1 A total of nineteen sub-samples were prepared for diatom assessment. These were comprised of two samples from BH13, two samples from BH14, and 15 samples from BH17.

4.5.2 Diatom preparation followed standard techniques (Battarbee et al. 2001). Two coverslips were made from each sample and fixed in Naphrax for diatom microscopy. A large area of the coverslips on each slide was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination.

4.5.3 Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Van der Werff & Huls (1957-1974), Hartley et al. (1996), Krammer & Lange-Bertalot (1986-1991) and Witkowski et al. (2000). Diatom species' salinity preferences are indicated using the halobian groups of Hustedt (1953, 1957), these salinity groups are summarised as follows:

- 1. Polyhalobian: marine >30 gl-1 salinity
- 2. Mesohalobian: brackish 0.2-30 gl-1 salinity
- 3. Oligohalobian - Halophilous: optimum in slightly brackish water

- 4. Oligohalobian - Indifferent: optimum in freshwater but tolerant of slightly brackish water
- 5. Halophobous: exclusively freshwater
- 6. Unknown: taxa of unknown salinity preference.

4.5.4 The full report on the diatom assessment is shown in **Appendix 5**.

4.6 Foraminifera and ostracods

4.6.1 A total of nineteen sub-samples from the retained boreholes were prepared for foraminifera and ostracod assessment. These were comprised of two samples from BH13, two samples from BH14, and 15 samples from BH17. The full report on the foraminifera and ostracod is presented in **Appendix 6**.

4.6.2 The sub-samples were weighed, then broken into small pieces by hand, placed into ceramic bowls, and dried in an oven. Boiling-hot water was then poured over them and a small amount of sodium carbonate added to help disaggregate the clay fraction. Each sub-sample was left to soak overnight. Washing was with hand-hot water through a 75 micron sieve, with the remaining residue being returned to the ceramic bowl for final drying in the oven. The residues were then stored in labelled plastic bags.

4.6.3 For examination, each sample was placed in a nest of sieves (>50, >250, >150µm, and base pan) and thoroughly shaken. Each grade was then sprinkled onto a picking tray, a little at a time, and viewed under a binocular microscope. “Contained material” were logged on a presence(x)/absence basis as shown in accompanying tables.

4.6.4 In only one core (VC-T15) was there a sufficient sequence in which the ‘contained material’ (which would contribute to the environmental reconstruction) and the foraminifera and ostracods could be logged and this is shown in **Appendix 6**.

4.6.5 The abundance of each foraminifera and ostracod species was estimated semi-quantitatively (one specimen, several specimens, common and abundant/superabundant) by experience and by eye. Species identification comes from Murray (2006) for the foraminifera, Athersuch et al. (1989) for the brackish and marine ostracods, and Meisch (2000) for the freshwater ostracods, in addition to expert judgement.

5 RESULTS

5.1 Radiocarbon dating

5.1.1 All the samples were successfully measured, providing results for the Late Mesolithic period (**Table 3**).

Table 3 Radiocarbon dating results.

Bore hole	Depth (mbgl)	Provenance	Laboratory reference	Material	Radiocarbon Age (BP)	Calibrated date range (95% probability)	Modelled date range (68% probability)
BH13	5.96-5.98	base of peat	UBA-53683	Waterlogged plant remains: *Quercus* sp. cupule fragment (small sample)	6012±45	5030–4790 cal. BC	*4990–4840 cal. BC*

Bore hole	Depth (mbgl)	Provenance	Laboratory reference	Material	Radiocarbon Age (BP)	Calibrated date range (95% probability)	Modelled date range (68% probability)
	5.64-5.66	top of peat	UBA-53682	Waterlogged plant remains: Unidentifable wood fragment	5150±32	4040–3810 cal. BC	*4040–3815 cal. BC*
BH14	6.92-6.94	base of peat	UBA-53685	Waterlogged plant remains: Tree leaf budscales (small sample)	6239±40	5310–5060 cal. BC	*5305–5075 cal. BC*
	6.57-6.59	top of peat	UBA-53684	Waterlogged plant remains: Tree leaf budscales	5571±33	4480–4350 cal. BC	*4445–4360 cal. BC*
BH17	9.53-9.55	base of organic alluvium	UBA-53687	Waterlogged plant remains: *Phragmites australis* leaves	5485±35	4440–4250 cal. BC	*Outlier*
	6.66-6.68	organic alluvium	UBA-53686	Waterlogged plant remains: *Alnus glutinosa* cone	5806±34	4780–4550 cal. BC	–
W-BH-35	5.13-5.15	peat	UBA-53688	Waterlogged plant remains: cf. *Prunus* sp. roundwood fragment	5356±34	4330–4050 cal. BC	–

5.1.2 The formation of the peat deposits in the area of BH13 started between 4990–4840 cal. BC (UBA-53683, 6012 ± 45 BP) and ended by 4040–3815 cal. BC (UBA-53682, 5150 ± 32 BP).

5.1.3 In the area of BH14, peat formation started between 5305–5075 cal. BC (UBA-53685, 6239 ± 40 BP) and ended by 4445–4360 cal. BC (UBA-53684, 5571 ± 33 BP).

5.1.4 Two radiocarbon dates were obtained for the organic alluvium deposits in BH17, but the results were not conformable: the measurement for the base of the deposit, of 4440–4250 cal. BC (UBA-53687, 5485 ± 35 BP) is younger than the date from c. 2.90 m higher up in the sequence, of 4780–4550 cal. BC (UBA-53686, 5806 ± 34 BP). Although measurements obtained on materials deposited on alluvial sediments can be unreliable due to the possibility of reworking of older materials, in this case it is likely that the nature of the dated samples is the main factor in the disagreement: common reed (*Phragmites australis*) rhizomes can penetrate very deep in sequences.

5.1.5 A date of 4330–4050 cal. BC (UBA-53688, 5356 ± 34 BP) was obtained for the peat deposit in W-BH35.

5.2 Plant macroremains

Introduction

5.2.1 A total of seven sub-samples from BH13 (two sub-samples), BH14 (two sub-samples), BH17 (two sub-samples) and W-BH35 (one sub-sample) were processed for assessment of plant macroremains. The results of the plant macroremains assessment are shown in **Appendix 2** and summarised below.

BH13

5.2.2 Two sub-samples were taken from the peat in borehole BH13. Moderately low quantities of waterlogged plant macroremains and wood fragments were present in the samples, together with common insect fragments within the upper sample. The preservation of plant macroremains in both samples was very poor, with mineral-staining on all organic remains. None of the fragments of wood could be identified to family, genus or species level.

5.2.3 The lower sample (5.96-5.98 m bgl) is largely wood fragments. However, indeterminable vegetative matter, deciduous leaf fragments, monocot/herbaceous stems and rhizomes, including some of which derive from *Phragmites australis* (common reed), and charcoal. Roots/rootlets were uncommon. A single cupule of *Quercus* (oaks) was present in the sample.

5.2.4 The upper sample (5.64-5.66 m bgl) is largely wood fragments and monocot/herbaceous stems and rhizomes, including some which derive from *Phragmites australis.* Indeterminable vegetative matter and roots/rootlets were also present, as were seeds of Lamiaceae (mint family).

BH14

5.2.5 Two sub-samples were assessed for plant macroremains from the peat in borehole BH14. The preservation in the upper sample was good, with plant macroremains and Coleoptera (beetle) fragments included, and the preservation in the lower sample was poor.

5.2.6 The lower sample (6.92-6.94 m bgl) had frequent wood fragments and deciduous leaf buds/budscales, in addition to monocot/herbaceous stems and rhizomes, which included *Phragmites australis* material and deciduous leaf fragments. Plant material included fruitlets of *Ranunculus* subgenus *Batrachium* (crowfoots) and fruits of *Lemna* sp. (duckweeds). Coleoptera fragments were present, but rare.

5.2.7 The upper sample (6.57-6.94 m bgl) was dominated by monocot/herbaceous stems and rhizomes, which included *Phragmites australis* material, deciduous leaf buds/budscales and moss stems and leaflets. Wood fragments and deciduous leaf fragments were also common. The infructescence, bracts and fruit of *Alnus glutinosa* (alder), fruits of *Carex* (sedges), fruits of *Juncus* (rushes) and fruitlets of *Mentha* cf. *aquatica* (cf. water mint) and Lamiaceae were also recorded in this sample.

BH17

5.2.8 Two sub-samples were assessed for plant macroremains from the organic alluvium in borehole BH17. The preservation of the upper sample was good, while the preservation for the lower sample was fair/poor. The plant macroremains reflect this, with a greater floral abundance and diversity within the upper sample.

5.2.9 The lower sample (9.53-9.55 m bgl) was dominated by monocot/herbaceous stems, including *Phragmites australis* stems and rhizomes. Moss stems and leaflets were also frequent. The only plant material identifiable to taxon level were fruit of Poaceae (grasses). Marine shell fragments were common, terrestrial/freshwater shell fragments and Coleoptera fragments were frequent. Fish teeth and Diptera (true flies) pupae were rare.

5.2.10 The upper sample (6.66-6.68 m bgl) was dominated by moss stems and monocot/herbaceous stems, including that of *Phragmites australis*. Deciduous leaf buds/budscales were frequent. Identifiable plant macroremains were frequent fruit of *Schoenoplectus* sp. (club-rushes), frequent fruit of *Carex* sp. and Cyperaceae, seeds of *Juncus* sp., rare infructescence, fruits and bracts of *Alnus glutinosa*, rare fruit of *Prunus* *spinosa* (blackthorn), rare fruitlets of Lamiaceae and rare fruit of Poaceae (grasses). Oribatida (moss mites) were frequent and Trichoptera (caddisflies) were rare in this sample.

W-BH35

5.2.11 A single sub-sample (5.13-5.15 m bgl) was assessed for plant macroremains from the peat in W-BH35. Preservation was fair and dominated by wood fragments. Moss stems and leaflets and monocot/herbaceous stems, including *Phragmites australis* were frequent. The only identifiable plant macroremains were rare fruits of *Prunus spinosa*. Trichoptera larval cases were present, but rare.

5.3 Pollen and spores

Introduction

5.3.1 A total of 25 sub-samples of 5 ml volume were processed using standard pollen extraction methods (see Branch et al. 2005). Five sub-samples were taken from BH13, five samples from BH14 and 15 samples were taken from BH17. The tabulated results of the pollen assessment are shown in **Appendix 3** and summarised below.

BH13

5.3.2 Five samples were assessed from the peat within borehole BH13. Pollen preservation varied across the samples, with good to good/moderate preservation within the upper samples (5.62-5.80 m bgl) and poor preservation in the lower samples (5.90-5.99 m bgl). Pollen concentration was moderate in the uppermost sample (5.62 m bgl) and was poor in the lower four samples. Assessment pollen counts were not reached in any samples within this borehole.

5.3.3 The pollen assemblage shows relatively little change during the sequence, being dominated by woody taxa comprising *Corylus-Myrica type* (hazel/bog myrtle), with lower relative abundances of *Quercus* (oaks), *Tilia* (limes) and *Alnus* (alders). *Pinus* (pines) was present at lower relative abundances in these upper samples. Herbaceous taxa are uncommon, with the dominant taxa being Poaceae (grasses), Cyperaceae (sedges) and Amaranthaceae (goosefoot family).

5.3.4 There is little fluctuation in the pollen assemblage in the upper four samples (5.62-5.90 m bgl), with tree and shrub taxa representing 65-89% of the pollen assemblage. Within the basal sample (5.99 m bgl), only 11 pollen grains were encountered within four traverses of the slide, with high counts of exotic *Lycopodium* grains. Grains encountered showed poor preservation.

5.3.5 Fern spores were present throughout the core at low concentrations, and included *Polypodium* (polypodies), *Dryopteris filix-mas* type (male fern type) and Pteropsida undifferentiated (fern sp.). Fern spores showed no trends.

5.3.6 No aquatic pollen grains were encountered within BH13.

5.3.7 Charcoal clasts were rare or absent throughout the core. Framboidal pyrite clasts were common to abundant within the samples, with the exception of 5.72 m bgl, where pyrite clasts were rare.

BH14

5.3.8 Five samples were assessed from the peat within BH14. Pollen preservation varied across the core, being Excellent/Good to Moderate in the upper samples (6.55-6.85 m bgl) and Moderate/Poor in the basal sample (6.95 m bgl). Pollen concentrations varied across the core, being Excellent/Good to Good/Moderate within samples at 6.55 m bgl, 6.75 m bgl and 6.85 m bgl. At 6.65 m bgl concentrations were Moderate/Poor and at 6.95 m bgl concentrations were Poor. Assessment pollen counts were achieved in three of five samples within this sequence.

5.3.9 The pollen assemblage throughout the sequence was dominated by woody taxa, with trees and shrubs having relative abundances of 76-91% in most samples (6.65-6.95 m bgl), and having relative abundances of 60% in the uppermost sample (6.55 m bgl). Woody taxa are dominated by *Quercus* and *Corylus* in the upper samples (6.55-6.65 m bgl), with *Tilia* and *Alnus* being present at lower relative abundances. Within the lower samples (6.75-6.85 m bgl) the assemblage becomes dominated by *Quercus, Tilia* and *Corylus*, but other tree taxa including *Alnus, Ulmus* (elms), *Salix* (willows) and *Fraxinus* (ash) are present at low abundances. In the basal sample concentrations of all taxa are low, with *Tilia* and *Quercus* being the dominant taxa.

5.3.10 Herbaceous taxa have relative abundances of 40% in the uppermost sample (6.55 m bgl) but declines to 9-24% in the lower samples. Herbaceous taxa are dominated by Poaceae, with lower concentrations of Cyperaceae, Amaranthaceae, *Plantago lanceolata* (Ribwort Plantain) and Ranunculaceae (buttercup family) throughout the core.

5.3.11 Fern spores are present throughout the sequence at low relative abundances, and include *Dryopterix filix-mas*, *Polypodium* and Pteropsida undifferentiated. Aquatics are very scarce throughout the core, represented by single grains of *Typha* (bulrush) at 6.55 and 6.75 m bgl.

5.3.12 Charcoal was absent throughout the sequence. Framboidal pyrite clasts were rare at 6.55 and 6.95 m bgl and absent from other samples.

BH17

5.3.13 Thirteen sub-samples were taken from organic silt and two sub-samples were taken from peat deposits from BH17. Pollen concentrations and preservation was typically good, although samples at 6.65 and 9.25 m bgl both concentration was classed as moderate/poor. Floral diversity was moderately high, with a mix of herbaceous and woody taxa present throughout the core, showing fluctuation in dominance. Typically, woody taxa had higher relative abundance (55-87%), than herbaceous taxa throughout the core. However, in the uppermost sample (5.31 m bgl) woody taxa only represented 32% of pollen.

5.3.14 Woody taxa were dominated by *Quercus* and *Corylus*, although *Pinus* and *Alnus* were present throughout the core. *Quercus* and *Corylus* were present at low abundances in the uppermost sample but increased within the deeper samples. *Tilia* was present at low abundances within the upper samples but increased slightly nearer the base of the core. *Betula* (birches) was present at low density within the upper sediments, being at low abundances or absent from deeper samples. Other woody taxa were present as single or occasional grains include *Acer* (maples)*, Fraxinus, Ilex* (Holly) and *Salix*.

5.3.15 Herbaceous plants were dominated by Poaceae, Cyperaceae and Amaranthaceae. Poaceae was frequent throughout the core but decreased slightly with depth. Cyperaceae was common within the uppermost sample but decreased to infrequent or absent with depth. Amaranthaceae were frequent throughout the core. Asteraceae (daisy family) were present throughout the core at low density. *Plantago lanceolata* (Ribwort Plantain) was frequent within the uppermost sub-sample, after which was present at low density.

5.3.16 Fern spores were present throughout the core, and are dominated by *Polypodium* and Pteropsida undifferentiated, although *Dryopteris filix-mas* type was present at low density in the lower samples.

5.3.17 Aquatics were present at low density throughout the core, typically represented by single grains of *Typha*. However, within the sample at 5.31 m bgl, *Typha* grains were the most common grain encountered.

5.3.18 Microscopic charcoal particles were present in low concentrations at 7.30, 7.60, 9.60 and 9.69 m bgl, and absent from all other samples. Framboidal pyrite was present as abundant or common within samples from the organic alluvium deposits, and occasional or rare within the basal peat unit.

5.3.19 Marine dinoflagellates and organic linings of foraminifera were present at low density throughout the sequence, including a single foraminiferal organic lining at the top of the peat. Reworked fern spores were present throughout the core, excluding the lowermost sample, reaching relatively high counts within the base of the organic alluvium.

5.4 Diatoms

Introduction

5.4.1 A total of nineteen sub-samples were prepared for diatom assessment. These were comprised of two samples from BH13, two samples from BH14, and 15 samples from BH17. The results of the diatom assessment are summarised in **Table 3** and presented in full in **Appendix 4**, with the full report on the results shown in **Appendix 5**.

BH13

5.4.2 Diatoms are present in both samples from borehole BH13. However, the numbers of diatoms present in these samples is extremely low and the quality of preservation very poor with low species diversity. There is therefore no further potential for percentage diatom analysis.

5.4.3 However, the diatom assemblages in BH13 are informative. The species represent brackish and marine habitats consistent with an estuarine environment. Marine taxa are represented by *Paralia sulcata* and *Opephora marina*. These planktonic taxa are probably allochthonous species from the outer estuary.

5.4.4 Brackish-marine diatoms are the benthic species *Diploneis didyma*, *Diploneis interrupta*, *Nitzschia granulata*, and *Nitzschia navicularis*. The planktonic estuary species *Cyclotella striata* is present in the sample from 5.46 m bgl.

BH14

5.4.5 A low number of diatoms is present in both samples from borehole BH14. The quality of valve preservation varies from poor to very poor, and species diversity is low. The potential for further diatom analysis is low or very low, however, the diatom assemblages shown in the assessment are useful in the interpretation of the sedimentary environment. The diatoms represent estuarine conditions and are dominated by taxa from shallow water, benthic habitats.

5.4.6 The marine-brackish, benthic species *Diploneis smithii* is common in the diatom assemblages of both samples. Other common brackish water benthic taxa include *Nitzschia navicularis, Nitzschia granulata* and *Diploneis interrupta*. The benthic brackish water diatoms *Caloneis westii*, *Diploneis didyma* and *Navicula peregrina* are present in the samples from 6.36 and 6.46 m bgl, with the estuary species *Cyclotella striata* also present in the latter sample.

BH17

5.4.7 Diatoms are present in all 15 samples from borehole BH17. The numbers of diatoms are generally very low or extremely low and the quality of preservation is poor to very poor, with extremely poor preservation at the bottom of the core. Species diversity is generally low with some moderately diverse assemblages, for example in the sample from 7.80 m bgl.

5.4.8 Overall, given the low diatom numbers and poor quality of preservation there is very low or no further potential for further, percentage diatom analysis. However, again the diatom assemblages shown from the assessment are useful in interpreting the sedimentary environment.

5.4.9 The coastal marine planktonic diatom *Paralia sulcata* is common or very common in all the samples from BH17. The exceptions are in sample 8.30 m bgl where *Paralia sulcata* is present, but the diatoms are very poorly preserved, and the species is represented by dissolved central areas; and the bottom sample 9.58 m bgl where *Paralia sulcata* is absent and the whole assemblage is very poorly preserved.

5.4.10 Other polyhalobous, marine diatoms present in BH17 samples include *Biddulphia aurita*, *Cymatosira belgica*, *Dimmeregramma minor*, *Grammatophora* sp., *Plagiogramma van-heurckii*, *Podosira stelligera*, *Rhabdonema* sp., *Rhaphoneis amphiceros*, *Rhaphoneis minutissima*, *Rhaphoneis* sp., *Rhaphoneis surirella*, *Thalassionema nitzschiodes* and *Trachyneis aspera*.

5.4.11 Marine-brackish diatoms in BH17 include the planktonic species *Actinoptychus undulatus* and *Thalassiosira decipiens* and the non-planktonic diatoms *Diploneis smithii, Navicula marina* and *Synedra gaillonii*.

5.4.12 A diverse range of mainly benthic, mesohalobous, brackish water diatom taxa are present throughout BH17. *Nitzschia navicularis* and *Nitzschia punctata* are present or common in some samples. Other mesohalobous benthic or non-planktonic diatoms present in BH17 include *Caloneis westii, Campylodiscus echeneis, Catenula adhaerans, Diploneis aestuari, Diploneis didyma, Diploneis interrupta, Navicula digitoradiata, Nitzschia granulata, Nitzschia hungarica, Scoliopleura brunkseiensis, Scoliopleura tumida* and *Synedra tabulata*. The planktonic brackish water species *Cyclotella striata* and *Actinocyclus normanii* were also present in several samples.

5.4.13 Freshwater diatoms are absent from BH17 except for the non-planktonic species *Diatoma mesodon* that was recorded in the sample at 6.80 m bgl.

5.4.14 The brackish and marine diatom assemblages of these samples have little or no further potential for further diatom analysis but are nevertheless informative in showing the persistence of an estuarine sedimentary environment.

Conclusions

5.4.15 Diatoms are present in all the samples; however, the number of diatoms and quality of preservation is generally poor. Throughout the diatom assemblages show the influence of tidal water with marine, marine-brackish, and brackish-marine diatoms comprising the entire assemblage.

5.4.16 The dominance of mesohalobous and allochthonous marine diatoms in the sediments is consistent with estuarine environments. Freshwater diatoms are absent except for the presence of a single valve in one sample.

Table 4 Summary of diatom evaluation results (+ present; - absent; fw – freshwater; bk – brackish; mar – marine; aero – aerophilous; mod – moderate; ex – extremely)

Borehole	Depth (m bgl)	Diatoms	Diatom Numbers	Quality of Preservation	Diversity	Assemblage type	Potential for % Count
BH13	5.46	+	ex low	v poor	low	bk mar	none
	5.56	+	ex low	v poor	low	bk mar	none
BH14	6.36	+	low	poor to v poor	low	bk mar-bk	low/some
	6.46	+	low	poor to v poor	low	bk mar-bk	v low
BH17	5.30	+	low	poor to v poor	low mod	mar bk	v low
	6.30	+	low	poor to v poor	low	mar bk	low
	6.55	+	v low	v poor	low	mar bk	none
	6.80	+	v low	v poor	low	bk mar fw	v low/none
	7.05	+	v low	v poor	low	mar bk	v low/none
	7.30	+	v low	v poor	low	mar bk	none/ex low
	7.55	+	v low	v poor to poor	low mod	mar bk	v low
	7.80	+	low	v poor to poor	mod	mar bk	low/v low
	8.05	+	v low	poor to v poor	low mod	mar bk	v low
	8.30	+	ex low	v poor	v low	mar bk	none
	8.55	+	ex low	v poor	low mod	bk mar	none/v low
	8.80	+	v low	v poor to mod	low mod	mar bk	none/v low
	9.05	+	v low	v poor	low mod	mar bk	none/low
	9.30	+	ex low	ex poor	low	bk mar	none
	9.58	+	v low	ex poor	low	bk	none

5.5 Foraminifera and ostracods

Introduction

5.5.1 A total of nineteen sub-samples were prepared for foraminifera and ostracod assessment, comprising two samples from BH13, two samples from BH14, and 15 samples from BH17. The results of the assessment are presented in **Appendix 6** and are summarised below.

BH13

5.5.2 Two samples were assessed from borehole BH13, both from near the base of an organic alluvial unit (context 133).

5.5.3 The *in situ* microfaunal assemblages recovered from these two samples are similar to those seen in BH17 (see below). The benthic foraminifera *Ammonia tepida*, *Elphidium williamsoni* and *Haynesina germanica* were present and as in BH17 indicate estuarine/tidal mudflat environments. These are accompanied by a diverse assortment of reworked benthic species probably of Miocene age similar to but more abundant than those seen in BH17. A number of reworked planktonic foraminifera were also recovered.

BH14

5.5.4 Two samples were assessed from borehole BH14, both from an organic alluvial unit (context 143). As only one specimen of the reworked benthic foraminifer *Cibicidoides* sp.

was recovered at 6.38-6.40 m bgl, no distribution chart is warranted. Rhomboidal crystals possibly of anhydrite were in abundance in this sample. There was no recovery from 6.48-6.50 mbgl.

BH17

5.5.5 A total of 15 samples were assessed from borehole BH17, spanning the full thickness of an organic alluvial unit (context 1704).

5.5.6 The isolated uppermost sample (5.32-5.34 m bgl) was devoid of microfossils save for a fragment of insect. Downhole from 6.32-6.34 m bgl to the base of the unit all samples except 8.57-8.59 m bgl yielded varying amounts of bivalve and gastropod fragments. No complete bivalves were recovered, and entire gastropods were rare. The molluscs have not been identified but may provide useful environmental information.

5.5.7 The section down to 8.32-8.34 m bgl was characterised by a low diversity assemblage of benthic foraminifera and ostracods. Specimens varied considerably in their states of preservation, and many had apparently suffered from sediment transport. All of the species recovered are typical of a brackish estuarine tidal/mudflat environment with no truly marine or freshwater species being found. Chief among the foraminifera are *Haynesina germanica*, *Elphidium williamsoni* and *Ammonia tepida*, while *Cyprideis torosa*, *Hirschmannia viridis* and *Leptocythere castanea* make up the ostracod component.

5.5.8 Some rare specimens are attributed to reworking of much older material (possibly Miocene sediments) through this interval. Again, this is typical of an estuarine environment.

5.5.9 Single diatom frustules were found at 7.07-7.09 and 7.32-7.34 m bgl but these have not been identified. Rare charophyte oogonia were seen at 8.32-8.34 and 9.32-9.34 m bgl indicating the presence of clear freshwater pools in the catchment. Seeds and megaspores were also observed in a few samples in this interval.

5.5.10 The sample from 8.57-8.59 m bgl was devoid of microfossils but yielded abundant rhomboidal crystals (?anhydrite) which may be of environmental significance. A few of these crystals were also present at 9.60-9.62 m bgl.

5.5.11 Except for a few specimens of foraminifera (some reworked) at 9.32-9.34 m bgl there is nothing of interest in the lower part of this unit.

6 DISCUSSSION

6.1.1 The palaeoenvironmental assessment results are considered collectively with reference to the aims and objectives outlined in **Section 3**. The lithostratigraphy of the deposits associated with the samples comprised:

- Glacial Till (Pleistocene);
- Peat (Holocene);
- Organic Alluvium (Holocene);
- Minerogenic Alluvium (Holocene).

6.1.2 Samples have been assessed from boreholes BH13, BH14, BH17 and W-BH35 for proxy paleoenvironmental indicators including pollen (organic alluvium, peat), plant macroremains (organic alluvium, peat), foraminifera (organic alluvium) and ostracods (organic alluvium).

6.2 Preservation and concentration of palaeoenvironmental remains

6.2.1 The preservation of palaeoenvironmental proxies was variable across the four boreholes, and between the peat and organic alluvium, ranging from good to poor. Below is a summary of the preservation and concentration of the palaeoenvironmental remains in the samples assessed.

Organic Alluvium

6.2.2 The organic alluvium was assessed in boreholes BH13, BH14 and BH17. The preservation of plant macroremains in the organic alluvium ranged from good to moderate/poor. Pollen preservation varied from moderate/poor to excellent, though was typically good in subsamples taken from the organic alluvium in BH17. Pollen concentrations reflected this, varying from moderate/poor to excellent, but was typically good.

6.2.3 Ostracods were absent from BH13 and BH14, and preservation and concentrations were generally low in BH17. Non-reworked foraminifera were absent from BH14 and were present in a low diversity assemblages in BH13 and BH17, with several samples containing very little or no foraminifera. Many of the microfossils present in these samples showed evidence of reworking. Diatom preservation was typically very poor to poor, with diatom concentrations low to extremely low throughout BH13, BH14 and BH17.

6.2.4 The variable preservation of samples within the organic alluvium is typical of that in sediments associated with estuarine environments. Microfossils and plant material would have likely been transported to at least some degree prior to deposition, via fluvial and/or tidal processes. These transport processes have led to an increase in damage to grains and poorer preservation. This is supported by a moderately diverse assemblage of reworked foraminifera and reworked spore grains.

6.2.5 Despite evidence for transportation of microfossils, depositional conditions were still likely anoxic, resulting in good preservation of organic microfossils such as pollen, and the formation of framboidal pyrite within the sediment, which occurs in reducing conditions.

Peat

6.2.6 Preservation of palaeoenvironmental (pollen and plant macroremains) from the peat deposits varied between boreholes, from poor to good. Within BH13, plant macroremains showed poor preservation within both samples, with mineral staining present on all organic remains. Pollen preservation in the upper three samples of this sequence was good to moderate/good, but poor in the lower two samples, with occasional corroded grains encountered. Pollen concentration was poor in all samples from BH13.

6.2.7 Plant macroremains from BH14 and W-BH35 showed good to poor preservation. Pollen preservation from BH14 ranged from good/excellent to moderate/poor, while in BH17 preservation was excellent to excellent/good. Pollen concentrations reflected this, ranging from excellent/good to poor.

6.2.8 Peat often forms in anoxic conditions, leading to good preservation of organic remains such as pollen and plant macroremains. However, post-depositional processes (such as fluctuating water tables) can cause degradation of organic remains, which can affect preservation and concentration.

6.3 Depositional environment and vegetation history

6.3.1 The program of palaeoenvironmental assessment and scientific dating has focused on the deposits of high palaeoenvironmental potential, namely the sequence of Holocene alluvium overlying the Pleistocene glacial till – including the peat and organic alluvium. The results of rangefinder radiocarbon dating of these deposits place the formation of these deposits into the Late Mesolithic.

6.3.2 The basal superficial geological deposit at the Site, forming the template upon which the alluvial sequence has accumulated, is the Pleistocene till. The till at the Site was typically greater than 10 m in thickness, representing a variable surface from c. -4 m OD in the west to c. -8 m OD in the east (Wessex Archaeology 2023). In North Lincolnshire and North Yorkshire, sediment deposition associated with glaciation is prevalent during the Devensian (MIS 4-2; 110-11.7 Kya). The North Sea Ice Lobe, dated to the Dimlington Stadial (MIS 2, 15-26 Kya) is interpreted as the source for the glacial till at the Site; the maximum glacial extent of the North Sea Ice Lobe is dated to approximately 17 Kya (Bateman 2015).

6.3.3 Following the retreat of the ice sheets after c. 13 Kya, sea levels rose rapidly, creating steep-sided valleys up to 9 m deep (Van de Noort 2004), which have now largely been infilled by Holocene sediments. This sea level rise would have resulted in the deposition of the estuarine alluvium encountered overlying the glacial till at the Site.

6.3.4 Organic-rich alluvium and relatively thin (<1 m thick) peat deposits were recorded within the alluvial sequence at the Site during the geoarchaeological borehole survey (Wessex Archaeology 2023). The peat deposits are generally recorded directly overlying the till at the base of the Holocene alluvium, and are present at variable elevations between c. -3 and -5 m OD. They represent reed swamp, sedge fen and alder carr environments (see below), forming in a wider environment of estuarine saltmarsh and mud flats in response to background sea-level rise. Peat is generally absent in the eastern part of the Site, and only locally present on the Pipeline Corridor. Given the localised nature of the peat (**Figure 3**), these sediments may have accumulated in localised backwaters or abandoned channels within a wider saltmarsh environment.

6.3.5 Peat deposits across the Site have been dated to the late Mesolithic, which is typical for the Humber Estuary, where they generally date from the late Mesolithic to the Bronze Age. Typically those deposits are often thinner closer to the foreshore of the Humber, where marine and estuarine conditions would have largely prevailed and increase in thickness towards the interior of the intertidal wetlands. Basal peats occurring at similar elevations to the present Site (c. -2 to -3 m OD) at South Ferriby (4.3 km west of Barton upon Humber) have been dated to approximately 5000 cal BC (Van de Noort & Fletcher 2000), forming at a similar interval as the peats on the Site.

6.3.6 As a whole, the pollen and plant macroremain assessments are indicative of sedge fen/reed swamp environments during the accumulation of the peat, with taxa including sedges, reeds and bulrushes, with isolated areas of alder carr. Reed swamp may have been more prevalent on the wider floodplain, whilst the dryland appears to have been dominated by mixed deciduous woodland including oak, lime and hazel, consistent with a mid-Holocene date for the deposits.

6.3.7 There is significant evidence from Mesolithic Britain for human impact across all landscape zones, including repeated evidence for burning of lowland coastal vegetation communities such as reed swamp (e.g. Bell 2007; Innes et al 2011). Such examples include microcharcoal evidence from palynological slides and microcharcoal remains indicating burning of reeds at Mesolithic sites such as Star Carr and Goldcliff East (Dark 1988;

Cummins 2000; 2002, Bell 2007). However, no specific indicators of human activity was identified in the pollen or plant macroremain records from the Site.

6.3.8 Following the deposition of the peat, rising relative sea levels led to the accumulation of estuarine alluvium, forming thick sequences of both minerogenic and organic alluvium to a level of c. 1 to 2 m OD. These deposits can be correlated with widespread alluviation in the Humber Estuary. Tidal influence became more prominent in the area as sea levels continued to rise, with tidal encroachment increasing from the coast and travelling further inland starting from the Mesolithic, at c. 8000 BC, with encroachment at Holderness in 5000 cal BC, the lower Ancholme Valley in 4000 cal BC, and the Humberhead Levels in 2300 cal BC (Van de Noort & Fletcher 2000).

6.3.9 The organic alluvium, in places up to c. 5 m thick, likely reflects the continued presence of salt marsh and/or reworking of organic sediments and peat in the wider floodplain. Within these deposits a pollen assemblage of brackish and wooded conditions is indicated. Herbaceous plants were dominated by grasses and sedges, the latter likely growing on the floodplain in areas of salt marsh or sedge fen along with plants of the Amaranthaceae family, which include many species typical of saltmarshes, and occasional grains of thrift/sea lavenders. Plant macroremains included the fruits of sedges and club-rushes, both taxa which are common in both freshwater and saltmarsh environments.

6.3.10 The diatom, foraminifera and ostracod assemblage was comprised of species typical of estuarine environments in the upper part of the organic alluvium. Rare charophytes oospores were present in the deeper sediments, which are associated with clear freshwater-brackish pools. Within the palynological samples, occasional dinoflagellate cysts indicative of brackish conditions, and foraminiferal linings, indicate a marine influence upon the Site and are typical of estuarine conditions. At the base of the sequence, marine shells were common, with several bands recorded.

6.3.11 Framboidal pyrite (iron sulphide, FeS_2) is common within the palynological samples within the organic alluvium. Framboidal pyrite usually forms in iron-rich environments under reducing conditions, such as that in saltmarsh and coastal flats environments. Framboidal pyrite was also found within the top of the peat in BH14, and throughout the peat in BH13, where plant macroremains had a minerogenic coating.

6.3.12 Reworked foraminifera and spores were also recorded within the organic alluvium. Reworked microfossils are often present in estuarine environments due to the higher energy environment, which could erode sediments, including microfossils, out of the banks of the river and rework them into the alluvial sequence.

6.3.13 During the late Mesolithic, intertidal influence is likely to have reached the lower reaches of the tributaries draining into the Humber, which would result in thick estuarine deposits at localities nearer the mouth of the Humber. However, there was a freshwater input into the sediments, as indicated by charophyte oospores, Trichoptera larval cases and freshwater snails. Despite some evidence for a freshwater input into the Site, there was no evidence from the foraminifera or ostracod assemblage of any truly freshwater taxa, freshwater diatoms were represented by a single valve present, and no exclusive freshwater aquatic plants were present in the plant macroremains or pollen record. The minor freshwater influence which is present within the organic alluvium could reflect material washed down by fluvial processes.

6.3.14 Woody macroremains, including alder, were identified within the organic alluvium, indicating that terrestrial but damp, conditions were present local to the Site. Supported by a pollen assemblage dominated by oak, lime and hazel, which indicate the local area contained woodland, possibly representing forested banks close to the river and bordering the estuarine floodplain.

6.3.15 Tree and shrub pollen show evidence of a mixed woodland local to the Site, dominated by oak and hazel, though in the deeper sediments lime becomes more prominent. The native lime taxa (*Tilia cordata* and *T. platyphyllos*) are typically associated with primary woodlands, and lime experienced large declines during the Holocene, with many declines associated with removal of this primary forest (Grant et al 2011). Lime declines are largely associated with human clearance activity between 5000 and 3000 cal BP, during the Late Neolithic to Late Bronze Age. However, at some sites in Britain the decline in lime can be attributed to marine inundation, with declines from 7150 to 3400 cal BP (Grant et al 2011).

6.3.16 Lime declines associated with marine inundation can be either sharp due to rapid rise in sea level, or gradual, associated with the gradual extension of wetland communities into primary woodland. Given the associated increase in saltmarsh taxa, and lithological evidence of sea level rise within the sequence, it is possible that the decline in lime observed at the Site from the peat and through the organic alluvium could reflect marine inundation at the Site.

7 RECOMMENDATIONS

7.1 Summary

7.1.1 The main conclusions of the palaeoenvironmental assessment to date are summarised below. Appropriate recommendations are made for further analysis in **Section 7.2**,

7.1.2 The peat deposits at the Site formed during the Late Mesolithic within reed swamp or sedge fen environments, forming in response to background sea-level rise. Given the localised nature of the peat, these sediments may have accumulated in localised backwaters or abandoned channels within a wider saltmarsh environment.

7.1.3 The combined results of the palaeoenvironmental assessment are consistent with a sedge fen or reed swamp environment associated with the peat deposits, likely with areas of alder carr woodland on the wider floodplain. The dryland environment during the accumulation of the peat was dominated by mixed deciduous woodland, dominated by oak, lime and hazel, consistent with a mid-Holocene date for the deposits. No clear evidence for human activity was identified within the peat.

7.1.4 The thick sequences of estuarine alluvium overlying the peat can be correlated with widespread alluviation in the wider Humber Estuary. The estuarine alluvium includes organic alluvium that is in places up to c. 5 m thick, likely forming in salt marsh and/or reflecting the reworking (erosion and deposition) of organic sediments and peat from the wider floodplain into the alluvial sequence.

7.1.5 The results of the palaeoenvironmental assessment of the organic alluvium are consistent with salt marsh environments, with the pollen dominated by goosefoot family, grasses, and sedges, with a dryland vegetation of mixed deciduous woodland similar to that recorded in the peat. No clear evidence for human activity was identified within the organic alluvium, although low concentrations of microcharcoal of uncertain origin (i.e. natural or anthropogenic) were present in various samples.

7.2 Recommendations

7.2.1 Although the diatom assemblages recorded in the alluvial sequence are useful at the assessment stage, the low numbers of diatoms and poor quality of valve preservation means that there is little or no potential for further analysis of the diatoms.

7.2.2 Within the organic alluvium, preservation and concentration of ostracods and foraminifera was typically poor. Ostracods were absent from BH13 and BH14, and foraminifera showed a low diversity assemblage within BH13 and BH17, with no Quaternary foraminifera recorded in BH14. No further analysis of ostracods and foraminifera is therefore recommended.

7.2.3 Preservation of pollen and plant macroremains is generally good within the peat, with concentrations almost demonstrating some potential for further analysis, but preservation is variable within the organic alluvium. However, these deposits date to the Late Mesolithic, an interval which has widespread evidence of peat deposits within the Humber Estuary. As frequent, and often thicker, peat deposits spanning the same archaeological time spans are present elsewhere along the Humber, including sites with evidence of human occupation, the geoarchaeological potential of these deposits is lower. No further analysis of pollen or plant macroremains is therefore recommended.

REFERENCES

[14]Chrono 2019. '14Chrono Centre laboratory 14C pre-treatment protocols', http://14chrono.org/site/wp-content/uploads/2020/03/Lab_protocols.pdf (accessed 29.04.2024).

Athersuch J, Horne D J and Whittaker J E 1989 Marine and brackish water ostracods, in Kermack, D M and Barnes, R S K (eds) *Synopsis of the British Fauna (New Series)* no. 43. E J Brill, Leiden (for the Linnean Society of London and The Estuarine and Brackish-water Sciences Association), 359pp

Bateman, MD, Evans, DJA, Buckland, PC, Connell, ER, Friend, EJ, Hartmann, D, Moxon, H, Fairburn, WA, Panagiotakopulu, E, and Ashurst RA 2015 Last glacial dynamics of the Vale of York and North Sea loves of the British and Irish Ice Sheet. *Proceedings of the Geologist's Association*, 126 (6): 712-730.

Battarbee R W, Jones V J, Flower R J, Cameron N G, Bennion H B, Carvalho L and Juggins, S 2001 Diatoms, in J P Smol and H J B Birks (eds.) *Tracking Environmental Change Using Lake Sediments Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Dordrecht: Kluwer Academic Publishers, 155–202

Bayliss, A and Marshall, P. 2022. *Radiocarbon Dating and Chronological Modelling: Guidelines and Best Practice*. Historic England, London.

Bell M 2007 *Prehistoric Coastal Communities. https://doi.org/10.5284/1081717*

Bennett, K D. Whittington, G and Edwards, K J 1994 Recent plant nomenclatural changes and pollen morphology in the British Isles. *Quaternary Newsletter*, 73 (6), 1–6.

Branch, N, Turney, C, Canti, M & Clark, P 2005 *Environmental Archaeology: Theoretical and Practical Approaches (1 ed.)*. London: Hodder Arnold.

Bronk Ramsey, C. 2008. 'Deposition models for chronological records', *Quaternary Science Reviews*, 27(1-2), 42–60.

Bronk Ramsey, C. 2009. 'Bayesian analysis of radiocarbon dates', *Radiocarbon* 51, 337–360.

Bronk Ramsey, C. and Lee, S. 2013. 'Recent and planned development of the Program OxCal', *Radiocarbon* 55(2-3), 720–730.

Cappers R T J, Bekker R M and Jans J E A 2006 *Digital Seed Atlas of the Netherlands*. Groningen, Barkhuis Publishing

Cummins, GE 2000 Fire! Accidental or strategic use of fire in the early Mesolithic of the eastern Vale of Pickering. In Young R (eds) *Mesolithic Lifeways. Current Research in Britain and Ireland*. Leicester Archaeology Monograph 7, 75-84.

Cummins, GE 2002 *Impacts of hunter-gatherers on the vegetation history of the eastern Vale of Pickering, Yorkshire*. Unpublished PhD Thesis, Department of Geography, University of Durham.

Cushing, E J 1967 Evidence for differential pollen preservation in late Quaternary sediments in Minnesota. Review of Palaeobotany and Palynology 4, 87–101

Dark, P 1998 Palaeoenvironmental investigations. In Mellars, P and Dark, P *Star Carr in Context* Cambridge: McDonald Institute for Archaeological Research 111-181.

English Heritage 2011 *Environmental Archaeology: A Guide to the Theory, Practice of Methods, from Sampling and Recovery to Post-excavation* (second edition). Portsmouth, English Heritage

Gale, R. and Cutler, D. 2000. *Plants in Archaeology: identification manual of vegetative plant materials used in Europe and the southern Mediterranean to c. 1500*. Otley, Westbury and Royal Botanic Gardens, Kew.

Grant, MJ, Waller, MP and Groves, JA 2011 The Tilia decline: vegetation change in lowland Britain during the mid and late Holocene *Quaternary Science Reviews*, 30, 394-408

Hartley B, Barber H G, Carter J R and Sims P A 1996 *An Atlas of British Diatoms*. Biopress Limited, Bristol

Hather, J. G. 2000. *The Identification of Northern European Woods: a guide for archaeologists and conservators*. London, Archetype.

Hendey, N I 1964 *An Introductory Account of the Smaller Algae of British Coastal Waters. Part V. Bacillariophyceae (Diatoms)*. Ministry of Agriculture Fisheries and Food, Series IV.

Hill, M. O., Preston, C. D. and Roy, D. B, 2004 PLANTATT-attributes of British and Irish plants: status, size, life history, geography and habitats. Huntingdon: Centre for Ecology and Hydrology.

Historic England 2015 *Management of Research Projects in the Historic Environment: the MoRPHE project managers' guide*. Swindon, Historic England

Hustedt, F 1953 Die Systematik der Diatomeen in ihren Beziehungen zur Geologie und Okologienebst einer Revision des Halobien-systems. *Sv. Bot. Tidskr*., 47, 509–519

Hustedt, F 1957 Die Diatomeenflora des Fluss-systems der Weser im Gebiet der Hansestadt Bremen. *Ab. naturw. Ver. Bremen* 34, 181–440

Innes, JB, Blackford, JJ and Simmons, IG 2011 Mesolithic Environments at Star Carr, the Eastern Vale of Pickering and Environs: local and regional contexts. *Journal of Wetland Archaeology*, 11(1), 85-108

Krammer, K and Lange-Bertalot, H 1986-1991 *Bacillariophyceae*. Gustav Fisher Verlag, Stuttgart

Meisch, C 2000 Freshwater Ostracoda of Western and Central Europe in Schwoerbel, J. & Zwick, P. (eds) *Suβwasserfauna von Mitteleuropa, Band 8/3.* Spektrum Akadamischer Verlag, Heidelberg and Berlin

Murray J W 2006 *Ecology and Applications of Benthic Foraminifera.* Cambridge University

Reimer, P J, Austin, W E N, Bard, E, Bayliss, A, Blackwell, P G, Bronk Ramsey, C, Butzin, M, Cheng, H, Edwards, R L, Friedrich, M, Grootes, P M, Guilderson, T P, Hajdas, I, Heaton, T J, Hogg, A G, Hughen, K A, Kromer, B, Manning, S W, Muscheler, R, Palmer, J G, Pearson, C, van der Plicht, J, Reimer, R W, Richards, D A, Scott, E M, Southon, J R, Turney, C S M, Wacker, L, Adolphi, F, Büntgen, U, Capano, M, Fahrni, S M, Fogtmann-Schulz, A, Friedrich, R, Köhler, P, Kudsk, S, Miyake, F, Olsen, J, Reinig, F, Sakamoto, M, Sookdeo, A and Talamo, S 2020 The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62 (4), 725–57

Schweingruber, F. H. 1990 *Microscopic Wood Anatomy* (3rd edition). Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research

Stace, C 1997 *New flora of the British Isles* (2nd edition). Cambridge, Cambridge University Press

Stroh, PA, Walker, K, Humphrey, TA, Pescott, OL and Burkmar, RJ 2023 *Plant Atlas 2020: mapping changes in the distribution of the British and Irish Flora*. Princeton: Princeton University Press.

Van de Noort, R. & Fletcher, W. 2000 Bronze age humanecodynamics in the Humber estuary. In G. Bailey, R. Charles & N. Winder (eds) *Human Ecodynamics*, *Symposia of the Association for Environmental Archaeology* No 19, 47–54. Oxford: Oxbow Books.

Van de Noort, R 2004 *The Humber Wetlands: The Archaeology of a Dynamic Landscape.* Windgather Press, Macclesfield

Wessex Archaeology 2023 NH3 Immingham Green Energy Terminal Geoarchaeological Borehole Survey and Watching Brief on GI Works. Report ref. 271001.03, July 2023.

APPENDICES

Appendix 1: Sub-samples

Sample	Unit name	Depth from (m)	Depth to (m)	Assessment
BH13	Organic alluvium	5.46	5.48	Diatoms
BH13	Organic alluvium	5.48	5.50	Foraminifera/ostracod
BH13	Organic alluvium	5.56	5.58	Diatoms
BH13	Organic alluvium	5.58	5.60	Foraminifera/ostracod
BH13	Peat	5.62	5.63	Pollen
BH13	Peat	5.64	5.66	Plant macros/AMS
BH13	Peat	5.72	5.73	Pollen
BH13	Peat	5.80	5.81	Pollen
BH13	Peat	5.90	5.91	Pollen
BH13	Peat	5.96	5.98	Plant macros/AMS
BH13	Peat	5.99	6.00	Pollen
BH14	Organic alluvium	6.36	6.38	Diatoms
BH14	Organic alluvium	6.38	6.40	Foraminifera/ostracod
BH14	Organic alluvium	6.46	6.48	Diatoms
BH14	Organic alluvium	6.48	6.50	Foraminifera/ostracod
BH14	Peat	6.55	6.56	Pollen
BH14	Peat	6.57	6.59	Plant macros/AMS
BH14	Peat	6.65	6.66	Pollen
BH14	Peat	6.75	6.76	Pollen
BH14	Peat	6.85	6.86	Pollen
BH14	Peat	6.92	6.94	Plant macros/AMS
BH14	Peat	6.95	6.96	Pollen
BH17	Organic alluvium	5.30	5.32	Diatoms
BH17	Organic alluvium	5.31	5.32	Pollen
BH17	Organic alluvium	5.32	5.34	Foraminifera/ostracod
BH17	Organic alluvium	5.60	5.61	Pollen
BH17	Organic alluvium	6.30	6.31	Pollen
BH17	Organic alluvium	6.30	6.32	Diatoms
BH17	Organic alluvium	6.32	6.34	Foraminifera/ostracod
BH17	Organic alluvium	6.55	6.57	Diatoms
BH17	Organic alluvium	6.57	6.59	Foraminifera/ostracod
BH17	Organic alluvium	6.65	6.66	Pollen
BH17	Organic alluvium	6.66	6.68	Plant macros/AMS
BH17	Organic alluvium	6.80	6.82	Diatoms
BH17	Organic alluvium	6.82	6.84	Foraminifera/ostracod
BH17	Organic alluvium	6.95	6.96	Pollen
BH17	Organic alluvium	7.05	7.07	Diatoms
BH17	Organic alluvium	7.07	7.09	Foraminifera/ostracod
BH17	Organic alluvium	7.30	7.31	Pollen

BH17	Organic alluvium	7.30	7.32	Diatoms
BH17	Organic alluvium	7.32	7.34	Foraminifera/ostracod
BH17	Organic alluvium	7.55	7.57	Diatoms
BH17	Organic alluvium	7.57	7.59	Foraminifera/ostracod
BH17	Organic alluvium	7.60	7.61	Pollen
BH17	Organic alluvium	7.80	7.82	Diatoms
BH17	Organic alluvium	7.82	7.83	Foraminifera/ostracod
BH17	Organic alluvium	7.90	7.91	Pollen
BH17	Organic alluvium	8.05	8.07	Diatoms
BH17	Organic alluvium	8.07	8.09	Foraminifera/ostracod
BH17	Organic alluvium	8.20	8.21	Pollen
BH17	Organic alluvium	8.30	8.32	Diatoms
BH17	Organic alluvium	8.32	8.34	Foraminifera/ostracod
BH17	Organic alluvium	8.50	8.51	Pollen
BH17	Organic alluvium	8.55	8.57	Diatoms
BH17	Organic alluvium	8.57	8.59	Foraminifera/ostracod
BH17	Organic alluvium	8.82	8.84	Foraminifera/ostracod
BH17	Organic alluvium	8.85	8.86	Pollen
BH17	Organic alluvium	8.80	8.82	Diatoms
BH17	Organic alluvium	9.05	9.07	Diatoms
BH17	Organic alluvium	9.07	9.09	Foraminifera/ostracod
BH17	Organic alluvium	9.25	9.26	Pollen
BH17	Organic alluvium	9.30	9.32	Diatoms
BH17	Organic alluvium	9.32	9.34	Foraminifera/ostracod
BH17	Organic alluvium	9.53	9.55	Plant macros/AMS
BH17	Organic alluvium	9.58	9.60	Diatoms
BH17	Organic alluvium	9.60	9.61	Pollen
BH17	Organic alluvium	9.60	9.62	Foraminifera/ostracod
BH17	Peat	9.62	9.63	Pollen
BH17	Peat	9.69	9.70	Pollen
E-BH35	Peat	5.14	5.16	Plant macros/AMS

Appendix 2: Pollen

Table 1: BH13

Depth (cm)		**562**	**572**	**580**	**590**	**599**
Exotic		95	13	66	195	365
Trees	*Alnus*	9		2	1	
	Pinus	6		3	3.5	
	Quercus	9	7	10	6	1
	Tilia	3	1	4	17	1
	Corylus	35	10	8	11	3
	Ilex			1		
Herbs	Poaceae	2	6	11	4	2
	Cyperaceae	2	2	1	1	
	Amaranthaceae	2	1	2	7	4
	Plantago lanceolata	1		1		
	Rumex acetosa	1				
Indet.	Corroded				2	
Fern spores	*Dryopteris filix-mas*			1	1	2
	Polypodium	4	1	1	5	
	Equisetum		1			
	Monolete Psilate	2	2	5	3	4
Aquat.	*Typha latifolia*					
Sphagnum		7	1			
Charcoal		Rare/Absent	None	V. Rare	None	None
Pyrite		Common	Rare	Occasional	Abundant	Common
Preservation		GM	G	GM	P	P
Concentration		M	P	P	P	P

Key: Preservation – P = Poor, M = Moderate, G = Good, E = Excellent; Concentration - P = Poor, M = Moderate, G = Good, E = Excellent

Table 2: BH14

	Depth (cm)	655	665	675	685	695
	Exotic	**16**	**18**	**26**	**16**	**25**
Trees and Shrubs	*Alnus*	4	6	37	12	4
	Pinus	1	1	0.5	1	0.5
	Quercus	38	29	155	40	11
	Tilia	6	4	71	55	15
	Ulmus			4	2	
	Corylus	22	8	63	26	6
	Fraxinus			2	1	
	Salix			2		
	Hedera			1		
Herbs	Poaceae	39	7	13	12	6
	Cyperaceae	2	2	1	2	1
	Amaranthaceae	1	1	4		
	Aster				1	
	Lactuaceae	1				
	Polygala			1		
	Plantago lanceolata	2	2	1		
	Plantago media-major	1		1		
	Rubus type		1			
	Ranunculaceae	1	1	7		
	Rumex		1	3		
	Rumex acetosa			1		
Ferns	*Dryopteris filix-mas*	1		2		
	Polypodium	2		5	3	1
	Monolete Psilate	3	1	3	19	7
Aquat.	*Typha*	5	5	1	1	
	Sphagnum	1		1		
	Fungi spore			1		
	Charcoal	None	None	None	None	None
	Pyrite	Rare	None	None	None	Rare
	Preservation	GM	M	EG	M	MP
	Concentration	GM	MP	EG	GM	P

Key: Preservation – P = Poor, M = Moderate, G = Good, E = Excellent; Concentration - P = Poor, M = Moderate, G = Good, E = Excellent

Table 3: BH17

Depth (cm)		531	560	630	665	695	730	760	790	820	850	885	925	960	962	969
Exotic		173	143	144	202	109	154	157	142	202	214	162	194	52	82	37
Trees	*Alnus*	20	22	32	13	13	15	14	11	31	32	19	10	15	10	7
	Betula	5	2	5	1		1	1	3	3	4	2		1		4
	Pinus	11.5	5.0	10.0	5.5	5.0	8.5	6.5	6.5	9.5	14.0	8.0	9.5	21.0	14.0	2.5
	Quercus	14	29	18	20	17	30	23	53	55	75	35	16	66	57	34
	Tilia	1	1	5	4	2	2		4	5	13	3		10	5	7
	Acer										1					
	Fraxinus								1				3	2		
	Taxus							1	3							
Shrubs	*Corylus avellana*-type	16	30	58	21	31	36	46	82	87	108	47	26	61	54	48
	Ilex						1									
	Crataegus	1														
	Salix									1	1	1		2		
	Sambucus								1							
	Hedera helix														1	
	Ericaceae		1							1						
Cult	*Avena-Triticum*	4														
	Secale cereale	2														
Herbaceous	Poaceae	63	22	19	16	26	22	11	21	24	16	19	10	22	25	36
	Cyperaceae	52	5	4	2		7	6	4	2	5	10	10	7	6	6
	Ranunculaceae	3		2	5	1	1							2	1	
	Aster type	4		1		1	4			4	1	1	2			
	Cirsium	1				1	1									
	Centaurea nigra					1								1		
	Lactuceae	3	1				2		1	1		1			1	
	Serratula type		1													
	Caryophyllaceae	5	1													
	Silene	1														
	Amaranthaceae	24	7	13	5	10	31	7	10	11	8	24	17	9	4	2

	Lamiaceae						1									
	Filipendula	2														
	Fabaceae				1											
	Armeria type				1		1	1								
	Malvaceae													1		
	Rumex	3	2			1	2	2	1		1	4	1	1		2
	Rumex acetosa	1								1						
	Polygonum aviculare		1													1
	Plantago lanceolata	19	2	2	1		3		3	3	2	11	2	4	6	5
	Plantago media-major	11	1				1		1					1		1
	Rosaceae	2				1		1		2	1					
	Trifolium															1
	Urtica type										1			2		1
	Rubiaceae	1														
	Euphorbia?			1												
Indet.	Crumpled							1	1		1		1			
Ferns	*Dryopterus filix-mas*											1	1	2	2	
	Polypodium	4	2	4	2	1	3		1	5	10	6	2	6	5	1
	Pteridium	6	1	2	1	1	3		1			1	1	1	1	
	Pteropsida undiff. Monolete Psilate	3	2	6	6	2	6	2	5	11	10	13	8	19	5	4
	Pteropsida undiff. Trilete Echinate	2						2		2				1	1	
	Pteropsida undiff. Trilete Psilate										1					
	Thelypteris	1														
Aquatics	*Myriophyllum*	2														
	Potamogeton	1														
	Sparganium				1											
	Typha	234	3	3	2	1	3	2	1	1	1	11		2	4	3
Sphagnum															6	4
Reworked		4	1	11	1	11	12	7	6	8	24	30	45	12	4	
Ma rin	Foraminifera lining	1			2		4	1	1	1			3	1	2	

	Xandarodinium xanthum		1										1			
	Echinidinium sp.						1									
	Selanopemphix quanta		1													
Charcoal		None	None	None	None	None	Rare	Rare	None	None	None	None	None	Rare	None	Rare
Pyrite		Abundant	Abundant	Abundant	Abundant	Com.	Abundant	Abundant	Abundant	Abundant	Abundant	Abundant	Abundant	Frequent	Occasional	Rare
Preservation		G	GM	GM	GM	GM	G	G	G	G	G	M	MP	E	EG	E
Concentration		E	GM	GM	MP	M	G	GM	GM	G	G	G	MP	E	EG	G

Key: Preservation – P = Poor, M = Moderate,G = Good, E = Excellent; Concentration - P = Poor, M = Moderate, G = Good, E = Excellent

Appendix 3: Plant Macroremains

Site Name		IGET	IGET	IGET	IGET	IGET	IGET	IGET
Site Code		271001	271001	271001	271001	271001	271001	271001
Borehole		BH13	BH13	BH14	BH14	BH17	BH17	W-BH-35
Depth (mbgl)		5.64-5.66	5.96-5.98	6.57-6.59	6.92-6.94	6.66-6.68	9.53-9.55	5.13-5.15
Bulk volume (ml)		60	80	450	300	250	200	90
Net volume (ml)		40	50	200	100	125	65	50
Preservation		Very poor. Mineral-staining on all organic remains.	Very poor. Mineral-staining on all organic remains.	Good	Poor	Good	Fair/Poor	Fair
Sample Matrix (abundance)								
Wood fragments		A**	A***	A	A*	-	-	A***
Deciduous leaf fragments		-	A	A	B	-	-	-
Deciduous leaf buds/budscales		-	-	A*	A*	A	-	-
Moss stems & leaflets		-	-	A*	-	A**	A	A*
Monocot./Herbaceous stems incl. *Phragmites australis* rhizomes and stems		A**	A	A**	A	A*	A***	A
Indet. vegetative/organic matter		A	A*	-	-	-	-	-
Roots/rootlets		B	B	-	-	-	-	-
Charcoal		-	A	-	-	-	-	-
Plant macroremains								
(q) *Lemna* sp. (Duckweeds)	fruit	-	-	-	B	-	-	-
(q) *Ranunculus* subgenus *Batrachium* (Crowfoots)	fruitlet	-	-	-	A	-	-	-
(t) *Alnus glutinosa* (Alder)	infructescence	-	-	C	-	C	-	-
(t) *Alnus glutinosa* (Alder)	bract	-	-	B	-	C	-	-
(t) *Alnus glutinosa* (Alder)	fruit	-	-	B	-	C	-	-
(t) *Prunus spinosa* (Blackthorn)	fruit (nutshell)	-	-	-	-	C	-	C

(t) *Prunus spinosa* (Blackthorn)	wood	-	-	-	-	-	-	C
(t) *Quercus* sp. (Oaks)	cupule	-	C	-	-	-	-	-
(w) *Carex* sp. (Sedges)	fruit	-	-	A	-	A	-	-
(w) Cyperaceae undiff. (Sedge family)	fruit	-	-	-	-	A	-	-
(w) *Juncus* sp. (Rushes)	seed	-	-	B	-	B	-	-
(w) *Mentha* cf. *aquatica* (cf. Water Mint)	fruitlet	-	-	B	-	-	-	-
(w) *Schoenoplectus* sp.(Club-rushes)	fruit	-	-	-	-	A	-	-
(x) Lamiaceae (Mint family)	fruitlets	C	-	C	-	C	-	-
(x) Poaceae (Grasses)	fruit	-	-	-	-	C	C	-
Insect/Invertebrates & Other								
Coleoptera (Beetles)	frags.	A	-	A	B	-	A*	-
Oribatida (Acari) (Moss mites)	-	-	-	-	-	A	A	-
Trichoptera (Caddisflies)	larval case	-	-	-	-	C	-	C
Diptera (True flies)	pupae	-	-	-	-	-	C	-
Terrestrial / Freshwater Snails	shell	-	-	-	-	-	A*	-
Marine shell	shell frag.	-	-	-	-	-	A***	-
Fish	teeth	-	-	-	-	-	C	-

Appendix 4: Diatom assessment results

Borehole	BH13		BH14		BH17														
Depth (m bgl)	**5.46**	**5.56**	**6.36**	**6.46**	**5.30**	**6.30**	**6.55**	**6.80**	**7.05**	**7.30**	**7.55**	**7.80**	**8.05**	**8.30**	**8.55**	**8.80**	**9.05**	**9.30**	**9.58**
Polyhalobous																			
Biddulphia (Odontella) aurita																1	1		
Cymatosira belgica																1	1		
Dimeregramma minor												1							
Grammatophora sp.									1										
Opephora marina		1																	
Paralia sulcata	1				3	3	2	2	3	3	2	3	3	1	2	2	2	2	
Plagiogramma van-heurckii						1													
Podosira stelligera																			1
Rhabdonema sp.					1							1							
Rhaphoneis amphiceros									1	1	1	1				1			
Rhaphoneis minutissima					1														
Rhaphoneis sp.					1	1	1							1		1	1		
Rhaphoneis surirella					1	1	1			1		1	1			1	1		
Thalassionema nitzschiodes									1										
Trachyneis aspera								1											
Polyhalobous to Mesohalobous																			
Actinoptychus undulatus					1	1	1	1		1		1	1		1		1		
Diploneis smithii			2	3	1														1
Navicula marina						1					1				1		1	1	
Synedra gaillonii							1												
Thalassiosira decipiens																	1		
Mesohalobous																			
Caloneis westii			1					1								1		1	
Campylodiscus echeneis															1				1
Catenula adhaerans									1										
Cyclotella striata	1			1		1		1	1						1		1	1	2
Diploneis aestuari															1				

Borehole	**BH13**		**BH14**		**BH17**														
Depth (m bgl)	**5.46**	**5.56**	**6.36**	**6.46**	**5.30**	**6.30**	**6.55**	**6.80**	**7.05**	**7.30**	**7.55**	**7.80**	**8.05**	**8.30**	**8.55**	**8.80**	**9.05**	**9.30**	**9.58**
Diploneis didyma		1		1			1		1		1	1	1	1	1	1		1	1
Diploneis interrupta	1		2	1							1								
Navicula digitoradiata											1	1							
Navicula peregrina				1															
Nitzschia granulata		1	2		1		1	1			1			1					1
Nitzschia hungarica							1	1	1		1	1							
Nitzschia navicularis	1	1	2	2		1		1	2	1	1		1	1	2	1	1		2
Nitzschia punctata										1	1	1	2		1	1			
Scoliopleura brunkseiensis					1														
Scoliopleura tumida					1	1				1		1	1			1	1		
Synedra tabulata							1												
Mesohalobous to Halophilous																			
Actinocyclus normanii								1	1										
Oligohalobous Indifferent																			
Diatoma mesodon								1											
Unknown Salinity Group																			
Cocconeis sp.													1						
Diploneis sp.							1					1							1
Fragilaria sp.									1				1						
Gyrosigma sp.									1				1						
Inderminate centric sp.										1									
Inderminate pennate sp.														1					
Melosira sp.											1								
Navicula sp.				1									1						
Hantzschia								1											
Nitzschia sp.								1					1						
Stauroneis sp.					1							1	1						
Unknown naviculaceae				1				1							1	1		1	1

Appendix 5: Diatom report

Diatom assessment for NH3 Immingham Green Energy Terminal (IGET)

Nigel G. Cameron, Environmental Change Research Centre,
Department of Geography, University College London,
North-West Wing, Gower Street, London WC1E 6BT

Introduction

The Immingham Green Energy Terminal (IGET) lies on the south shore of the Humber Estuary. As part of a palaeoenvironmental assessment carried out by Wessex Archaeology, 3 borehole sequences with a total of 19 samples were selected for diatom assessment.

The diatom assessment considers the numbers of diatoms, the state of preservation of the diatom assemblages, species diversity, diatom species environmental preferences and the potential of the sediments for further diatom analysis.

Methods

Diatom preparation followed standard techniques (Battarbee *et al.* 2001). Two coverslips were made from each sample and fixed in Naphrax for diatom microscopy. A large area of the coverslips on each slide was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination.

Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Werff & Huls (1957-1974), Hartley *et al.* (1996), Krammer & Lange-Bertalot (1986-1991) and Witkowski *et al.* (2000). Diatom species' salinity preferences are indicated using the halobian groups of Hustedt (1953, 1957: 199), these salinity groups are summarised as follows:

1. Polyhalobian: >30 g l-1

2. Mesohalobian: 0.2-30 g l-1

3. Oligohalobian - Halophilous: optimum in slightly brackish water

4. Oligohalobian - Indifferent: optimum in freshwater but tolerant of slightly brackish water

5. Halophobous: exclusively freshwater

6. Unknown: taxa of unknown salinity preference.

Results & Discussion

The diatom samples, boreholes and depths are shown in Table 1.

Table 1. Immingham Green Energy Terminal (IGET) Diatom samples

Diatom sample	Borehole Number	Top Depth (m) bgl
D1	13	5.46
D2	13	5.56
D3	14	6.36
D4	14	6.46
D5	17	5.30
D6	17	6.30
D7	17	6.55
D8	17	6.80
D9	17	7.05
D10	17	7.30
D11	17	7.55
D12	17	7.80
D13	17	8.05
D14	17	8.30
D15	17	8.55
D16	17	8.80
D17	17	9.05
D18	17	9.30
D19	17	9.58

Table 2 shows a summary of the results from the diatom evaluation. The records of diatom taxa and their salinity classifications are shown in Table 3 (Excel file attached): 1 – present; 2 – common; 3 – more common.

Table 2. Summary of diatom evaluation results for Immingham Green Energy Terminal borehole samples (+ present; - absent; fw – freshwater; bk – brackish; mar – marine; aero – aerophilous; mod – moderate; ex – extremely)

Core & Diatom Sample Number	Diatoms	Diatom Numbers	Quality of Preservation	Diversity	Assemblage type	Potential for % Count
D1	+	ex low	v poor	low	bk mar	none
D2	+	ex low	v poor	low	bk mar	none
D3	+	low	poor to v poor	low	bk mar-bk	low/some
D4	+	low	poor to v poor	low	bk mar-bk	v low
D5	+	low	poor to v poor	low mod	mar bk	v low
D6	+	low	poor to v poor	low	mar bk	low
D7	+	v low	v poor	low	mar bk	none
D8	+	v low	v poor	low	bk mar fw	v low/none
D9	+	v low	v poor	low	mar bk	v low/none
D10	+	v low	v poor	low	mar bk	none/ex low
D11	+	v low	v poor to poor	low mod	mar bk	v low
D12	+	low	v poor to poor	mod	mar bk	low/v low
D13	+	v low	poor to v poor	low mod	mar bk	v low
D14	+	ex low	v poor	v low	mar bk	none
D15	+	ex low	v poor	low mod	bk mar	none/v low
D16	+	v low	v poor to mod	low mod	mar bk	none/v low
D17	+	v low	v poor	low mod	mar bk	none/low
D18	+	ex low	ex poor	low	bk mar	none
D19	+	v low	ex poor	low	bk	none

BH13 (Samples D1 and D2)

Diatoms are present in both samples from BH13. However, the numbers of diatoms present in these samples is extremely low and the quality of preservation very poor with low species diversity. There is therefore no further potential for percentage diatom analysis.

However, the diatom assemblages in BH13 are informative. The species represent brackish and marine habitats consistent with an estuarine environment. Marine taxa are represented by *Paralia sulcata* and *Opephora marina*. These planktonic taxa are probably allochthonous species from the outer estuary.

Brackish-marine diatoms are the benthic species *Diploneis didyma, Diploneis interrupta, Nitzschia granulata*, and *Nitzschia navicularis*. The planktonic estuary species *Cyclotella striata* is present in sample D1.

BH14 (Samples D3 and D4)

A low number of diatoms is present in both samples from BH14. The quality of valve preservation varies from poor to very poor, and species diversity is low. The potential for further diatom analysis is low or very low, however, the diatom assemblages shown in the assessment are useful in the interpretation of the sedimentary environment. The diatoms represent estuarine conditions and are dominated by taxa from shallow water, benthic habitats.

The marine-brackish, benthic species *Diploneis smithii* is common in the diatom assemblages of both samples. Other common brackish water benthic taxa include *Nitzschia navicularis, Nitzschia granulata and Diploneis interrupta*. The benthic brackish water diatoms *Caloneis westii, Diploneis didyma* and *Navicula peregrina* are present in D3 or D4 and the estuary species *Cyclotella striata* is present in D4.

BH17 (Samples D5 to D19)

Diatoms are present in all 15 samples from BH17. The numbers of diatoms are generally very low or extremely low and the quality of preservation is poor to very poor, with extremely poor preservation at the bottom of the core. Species diversity is generally low with some moderately diverse assemblages, for example in sample D12. Overall, given the low diatom numbers and poor quality of preservation there is very low or no further potential for further, percentage diatom analysis. However, again the diatom assemblages shown from the assessment are useful in interpreting the sedimentary environment.

The coastal marine planktonic diatom *Paralia sulcata* is common or very common in all the samples from BH17. The exceptions are in sample D14 where *Paralia sulcata* is present, but the diatoms are very poorly preserved, and the species is represented by dissolved central areas; and the bottom sample D19 where *Paralia sulcata* is absent and the whole assemblage is very poorly preserved.

Other polyhalobous, marine diatoms present in BH17 samples include *Biddulphia aurita, Cymatosira belgica, Dimmeregramma minor, Grammatophora* sp., *Plagiogramma van-heurckii, Podosira stelligera, Rhabdonema* sp., *Rhaphoneis amphiceros, Rhaphoneis minutissima, Rhaphoneis* sp., *Rhaphoneis surirella, Thalassionema nitzschiodes* and *Trachyneis aspera*.

Marine-brackish diatoms in BH17 include the planktonic species *Actinoptychus undulatus* and *Thalassiosira decipiens* and the non-planktonic diatoms *Diploneis smithii, Navicula marina* and *Synedra gaillonii*.
A diverse range of mainly benthic, mesohalobous, brackish water diatom taxa are present throughout BH17. *Nitzschia navicularis* and *Nitzschia punctata* are present or common in some samples. Other mesohalobous benthic or non-planktonic diatoms present in BH17 include *Caloneis westii, Campylodiscus echeneis, Catenula adhaerans, Diploneis aestuari, Diploneis didyma, Diploneis interrupta, Navicula digitoradiata, Nitzschia granulata,*

Nitzschia hungarica, Scoliopleura brunkseiensis, Scoliopleura tumida and *Synedra tabulata*. The planktonic brackish water species *Cyclotella striata* and *Actinocyclus normanii* were also present in several samples.

Freshwater diatoms are absent from BH17 except for the non-planktonic species *Diatoma mesodon* that was recorded in sample D8.

The brackish and marine diatom assemblages of these samples have little or no further potential for further diatom analysis but are nevertheless informative in showing the persistence of an estuarine sedimentary environment.

7.3 Conclusions

- A total of 19 samples from 3 boreholes have been assessed for diatoms. Diatoms are present in all the samples; however, the number of diatoms and quality of preservation is generally poor.
- Throughout the diatom assemblages show the influence of tidal water with marine, marine-brackish, and brackish-marine diatoms comprising the entire assemblage. The dominance of mesohalobous and allochthonous marine diatoms in the sediments is consistent with estuarine environments.
- Freshwater diatoms are absent except for the presence of a single valve in one sample.
- Although the diatom assemblages recorded throughout are useful at the assessment stage, the low numbers of diatoms and poor quality of valve preservation means that there is little or no potential for further, percentage diatom analysis of the sequences.

Acknowledgements

Thanks to Alex Brown of Wessex Archaeology for providing the borehole samples for diatom assessment from the Immingham IGET site.

<u>References</u>

Battarbee, R.W., Jones, V.J., Flower, R.J., Cameron, N.G., Bennion, H.B., Carvalho, L. & Juggins, S. 2001. Diatoms. In (J.P. Smol and H.J.B. Birks eds.), Tracking Environmental Change Using Lake Sediments Volume 3: Terrestrial, Algal, and Siliceous Indicators, 155-202. Dordrecht: Kluwer Academic Publishers.

Hartley, B., H.G. Barber, J.R. Carter & P.A. Sims. 1996. *An Atlas of British Diatoms.* Biopress Limited. Bristol. pp. 601.

Hendey, N.I. 1964 An Introductory Account of the Smaller Algae of British Coastal Waters. Part V. Bacillariophyceae (Diatoms). Ministry of Agriculture Fisheries and Food, Series IV. pp. 317.

Hustedt, F. 1953. Die Systematik der Diatomeen in ihren Beziehungen zur Geologie und Okologie nebst einer Revision des Halobien-systems. *Sv. Bot. Tidskr.*, 47: 509-519.

Hustedt, F. 1957. Die Diatomeenflora des Fluss-systems der Weser im Gebiet der Hansestadt Bremen. *Ab. naturw. Ver. Bremen* 34, 181-440.

Krammer, K. & H. Lange-Bertalot, 1986-1991. *Bacillariophyceae.* Gustav Fisher Verlag, Stuttgart.

Werff, A. Van Der & H. Huls. 1957-1974 *Diatomeenflora van Nederland*, 10 volumes

Witkowski, A, H. Lange-Bertalot & D. Metzeltin 2000. *Diatom Flora of Marine Coasts I.* Iconographia Diatomologica. Annotated Diatom Micrographs Ed. by H. Lange-Bertalot Vol. 7. A.R.G. Gantner Verlag. Koeltz Scientific Books. Königstein, Germany pp 92

Appendix 6: Foraminifera and ostracod report

BioChron

Geochronology
Biostratigraphy
Project management

Report No: 03/24 **11 June 2024**

Microfaunal assessment of borehole samples from NH3 Immingham Green Energy Terminal

by

John Athersuch

for

Wessex Archaeology

This report was written and compiled by BioChron, 17 Ottershaw Park, Chobham Road, Ottershaw, Surrey KT16 0QG

1 – Introduction

Nineteen samples from three borehole locations at the NH3 Immingham Green Energy Terminal site were provided by Wessex Archaeology for an assessment of ostracods and foraminifera from a unit of organic alluvium formed under the influence of rising sea levels during the Holocene. Recovery of these microfossils was poor but enough specimens were present to provide some useful environmental information.

Each sample was washed in water through a 125μm sieve, the resulting residue being dried at 100°C and subsequently examined under a reflected light microscope. Representative specimens were selected and stored on cardboard slides for later identification.

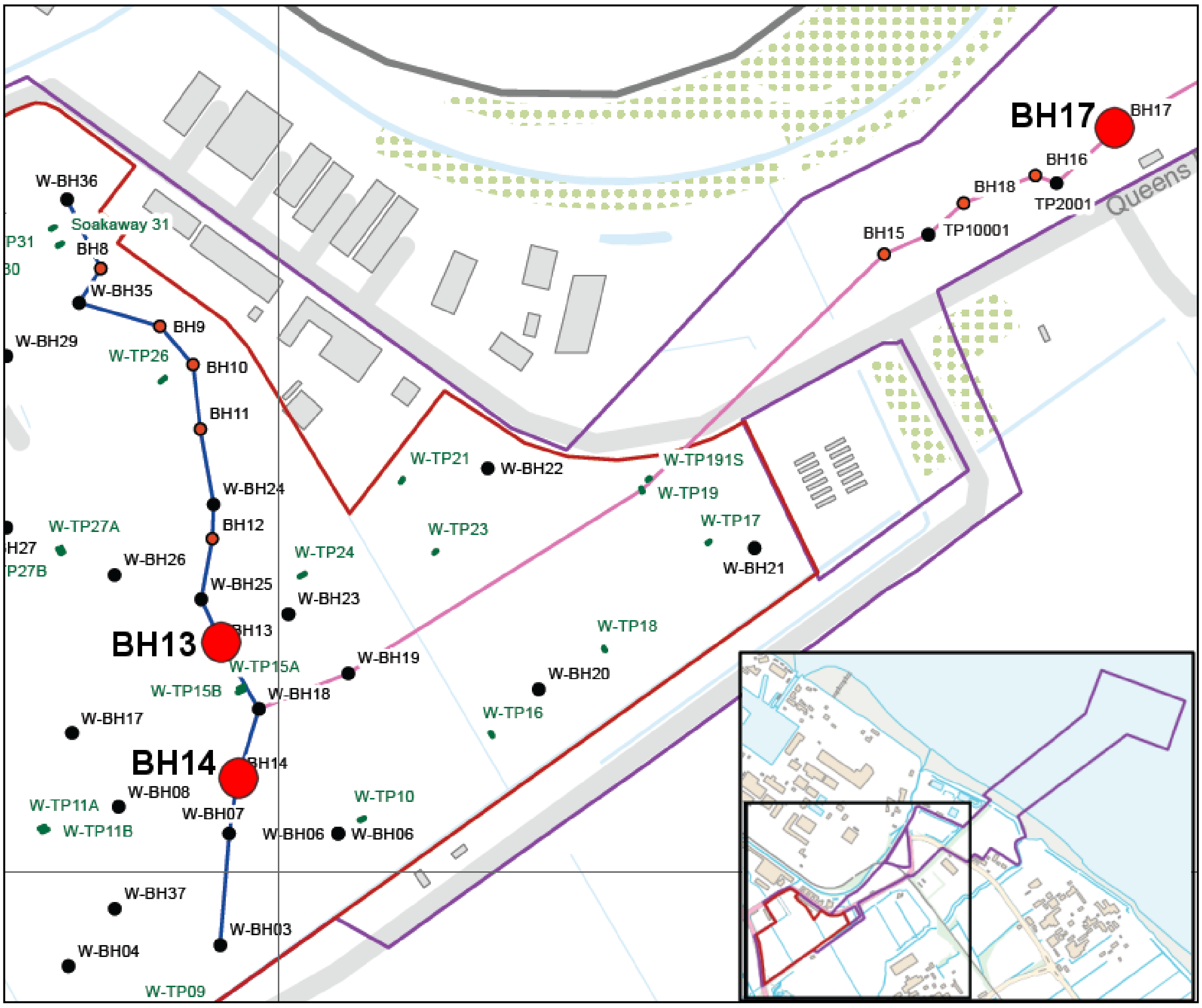


Figure 1: Location map showing (*inter alia*) the boreholes sampled in this assessment (red dots).

(extracted from Wessex Archaeology Document reference: 271001.03, September 2023.)

2 - Results of Assessment

Borehole 17 (Transect 4)

The results from this borehole are described first as 15 samples were assessed spanning the full thickness of an organic alluvial unit (context 1704). A record of the specimens recovered is provided in Figure 2 (key in Appendix).

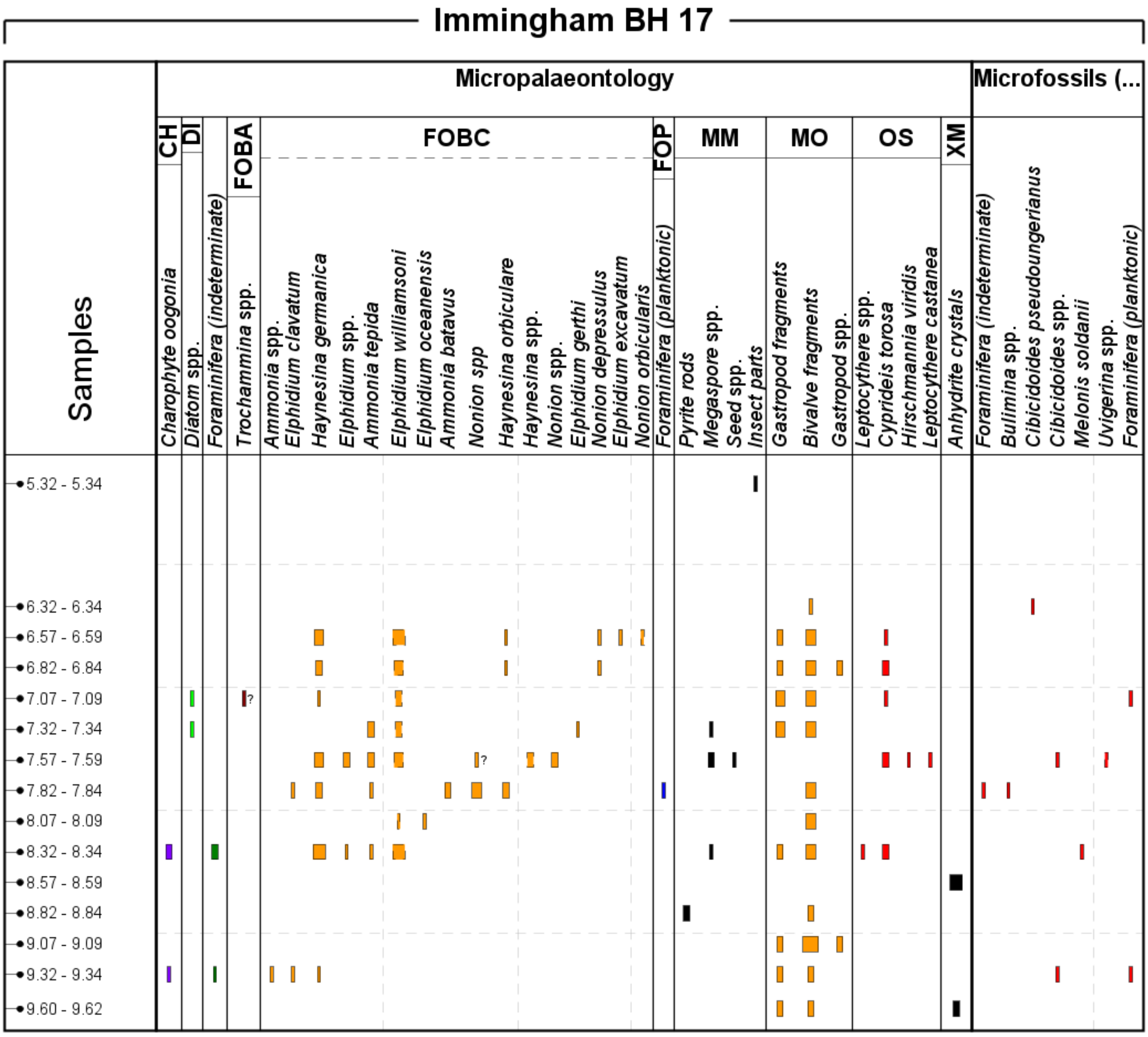


Figure 2: Distribution chart of microfossils recovered form Borehole 17

The isolated uppermost sample (5.32-5.34m) was devoid of microfossils save for a fragment of insect. Downhole from 6.32m-6.34m to the base of the unit all samples except 8.57-8.59m yielded varying amounts of bivalve and gastropod fragments. No complete bivalves were recovered and entire gastropods were rare. The molluscs have not been identified but may provide useful environmental information.

The section down to 8.32-8.34m was characterised by a low diversity assemblage of benthic foraminifera and ostracods. Specimens varied considerably in their states of preservation and many had apparently suffered from sediment transport. All of the species recovered are typical of a brackish estuarine tidal/mudflat environment with no truly marine or freshwater species being found. Chief among the foraminifera are *Haynesina germanica, Elphidium williamsoni* and *Ammonia tepida*, while *Cyprideis torosa*, *Hirschmannia viridis* and *Leptocythere castanea* make up the ostracod component.

Some rare specimens are attributed to reworking of much older material (possibly Miocene sediments) through this interval. Again this is typical of an estuarine environment.

Single diatom frustules were found at 7.07-7.09m and 7.32-7.34m but these have not been identified. Rare charophyte oogonia were seen at 8.32-8.34m and 9.32-9.34m indicating the presence of clear freshwater pools in the catchment. Seeds and megaspores were also observed in a few samples in this interval.

The sample from 8.57-8.59 was devoid of microfossils but yielded abundant rhomboidal crystals (?anhydrite) which may be of environmental significance. A few of these crystals were also present at 9.60-9.62m.

Except for a few specimens of foraminifera (some reworked) at 9.32-9.34m there is nothing of interest in the lower part of this unit.

Borehole 13 (Transect 2)

Only two samples were available from this borehole, both from near the base of an organic alluvial unit (context 133). A record of the specimens recovered is provided in Figure 3.

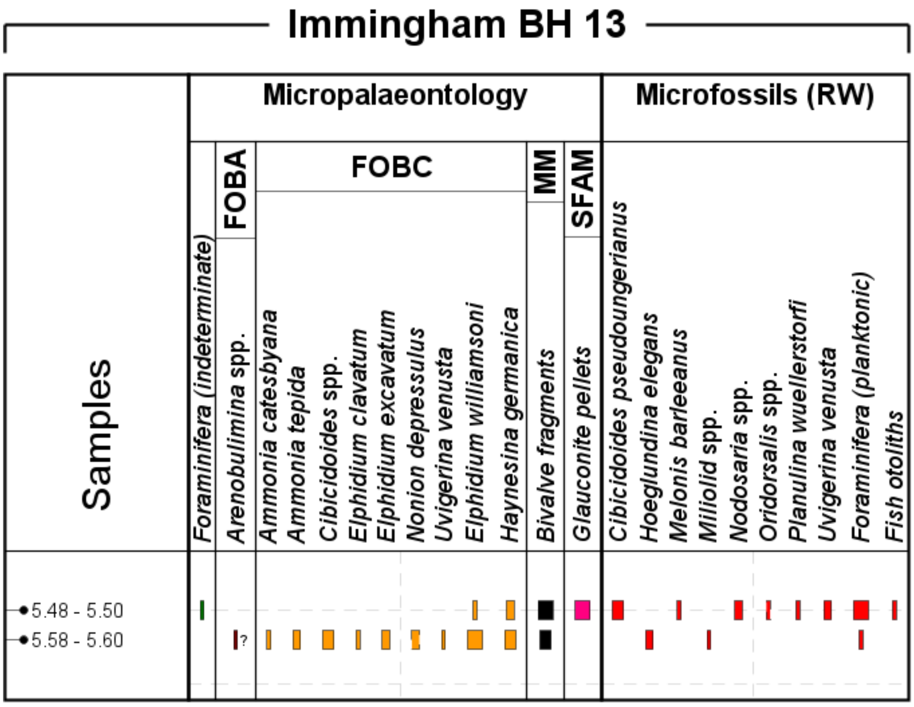


Figure 3: Distribution chart of microfossils recovered form Borehole 13

The *in situ* microfaunal assemblages recovered from these two samples are similar to those seen in Borehole 17. The benthic foraminifera *Ammonia tepida, Elphidium williamsoni* and *Haynesina germanica* were present and as in Borehole 17 indicate estuarine/tidal mudflat environments. These are accompanied by a diverse assortment of reworked benthic species probably of Miocene age similar to but more abundant than those seen in Borehole 17. A number of reworked planktonic foraminifera were also recovered.

Borehole 14 (Transect 2)

Only two samples were available from this borehole, both from an organic alluvial unit (context 143). As only one specimen of the reworked benthic foraminifer *Cibicidoides* sp. was recovered at 6.38-6.40m, no distribution chart is warranted. Rhomboidal crystals possibly of anhydrite were in abundance in this sample. There was no recovery from 6.48-6.50m.

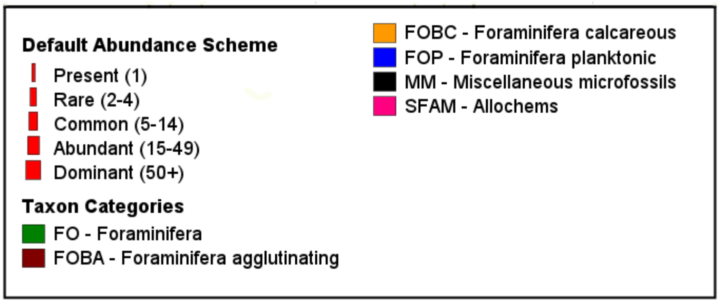
3 - References

Athersuch, J., Horne, D.J. and Whittaker, J.E., 1989. Marine and Brackish Water Ostracods. Synopses of the British Fauna (New Series) No. 43. eds. Kermack, D.M. & Barnes , R.S.K. The Linnean Society of London.

Murray, J.W. 1979. British Nearshore Foraminiferids. Synopses of the British Fauna (New Series) No. 16. eds. Kermack, D.M. & Barnes , R.S.K. The Linnean Society of London.

Wessex Archaeology, September 2023. NH3 Immingham Green Energy Terminal. Document reference: 271001.03.

Key to charts:

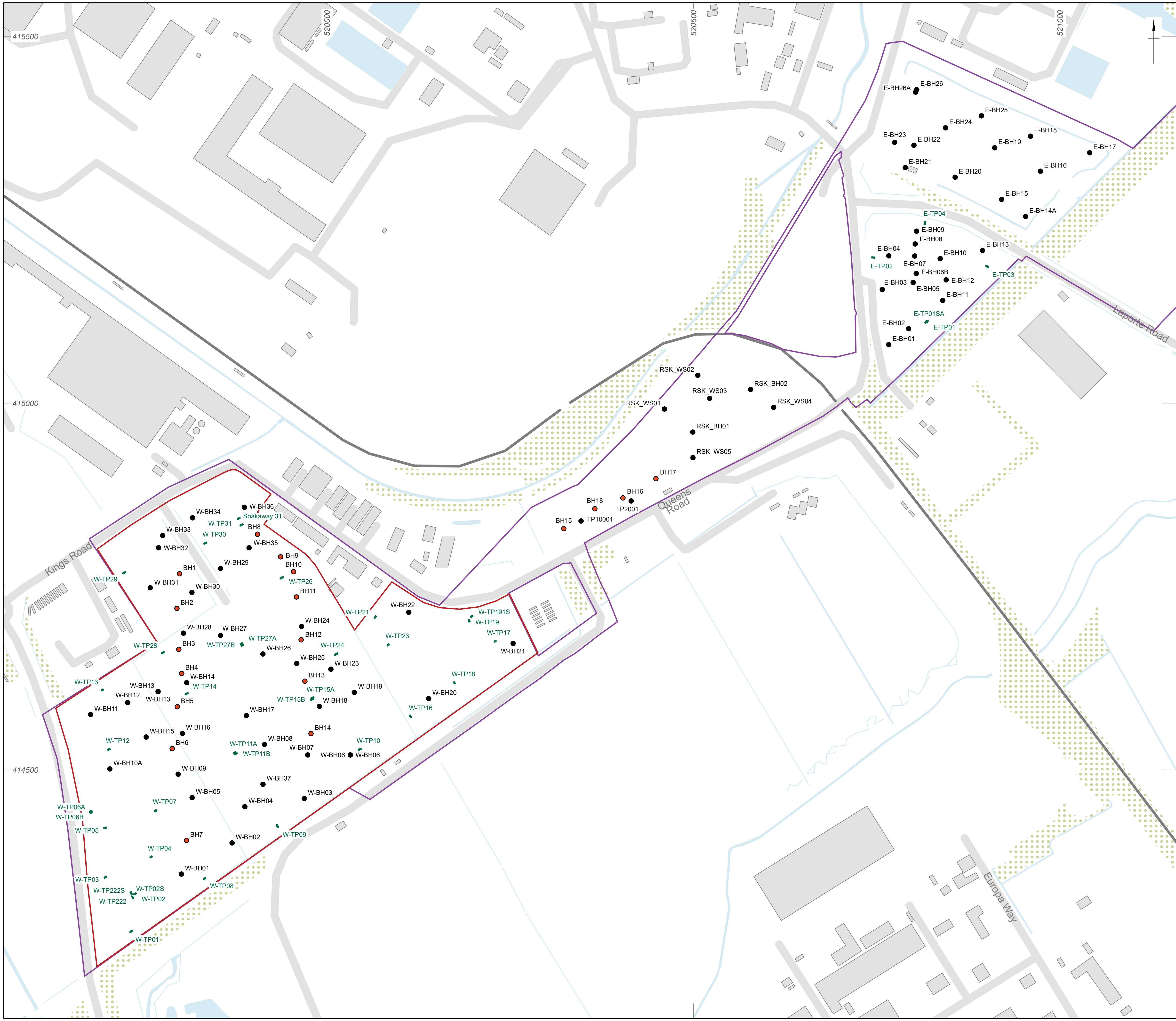


OASIS Summary for wessexar1-525353

OASIS ID (UID)	wessexar1-525353
Project Name	NH3 Immingham Green Energy Terminal Palaeoenvironmental Assessment Report
Sitename	NH3 Immingham Green Energy Terminal Palaeoenvironmental Assessment Report
Sitecode	271004
Project Identifier(s)	271004
Activity type	Environmental Sampling, Borehole Survey
Planning Id	
Reason For Investigation	Planning: Between application and determination
Organisation Responsible for work	Wessex Archaeology
Project Dates	01-Sep-2023 - 31-Dec-2023
Location	NH3 Immingham Green Energy Terminal Palaeoenvironmental Assessment Report NGR : TA 19890 14605 LL : 53.614280291974644, -0.189151851107036 12 Fig : 519890,414605
Administrative Areas	Country : England County/Local Authority : North East Lincolnshire Local Authority District : North East Lincolnshire Parish : Immingham
Project Methodology	Wessex Archaeology was commissioned by AECOM to produce a report on the palaeoenvironmental assessment of boreholes recovered during a geoarchaeological borehole survey at NH3 Immingham Green Energy Terminal, Immingham, North Lincolnshire. This report follows on from the results of the geoarchaeological borehole survey and deposit modelling, which recorded a sequence of Pleistocene glacial till, overlain by localised Holocene peat deposits, and more widespread organic alluvium and minerogenic alluvium. The peat and organic alluvium were highlighted as having high palaeoenvironmental potential, with targeted recommendations made for palaeoenvironmental assessment and radiocarbon dating. The principal aim of this report is to determine the age, nature and depositional history of the deposits recovered at the site, as well as the preservation potential of the palaeoenvironmental remains and their potential for further analysis.

Project Results	The peat deposits at the Site formed during the mid-Holocene, within reed swamp or sedge fen environments, forming in response to background sea-level rise. Radiocarbon dates of peat deposits from three boreholes have produced dates placing peat formation in the Late Mesolithic. Given the localised nature of the peat, these sediments may have accumulated in localised backwaters or abandoned channels within a wider saltmarsh environment. The combined results of the palaeoenvironmental assessment are consistent with a sedge fen or reed swamp environment associated with the peat deposits, likely with areas of alder carr woodland on the wider floodplain. The dryland environment during the accumulation of the peat was dominated by mixed deciduous woodland, dominated by oak, lime and hazel, consistent with a mid-Holocene date for the deposits. No clear evidence for human activity was identified within the peat. The thick sequences of estuarine alluvium overlying the peat can be correlated with widespread alluviation in the wider Humber Estuary. The estuarine alluvium includes organic alluvium that is in places up to c. 5 m thick, likely forming in salt marsh and/or reflecting the reworking (erosion and deposition) of organic sediments and peat from the wider floodplain into the alluvial sequence. Radiocarbon dating of the organic alluvium yielded dates of Late Mesolithic dates, although the basal date is an outlier. The results of the palaeoenvironmental assessment of the organic alluvium are consistent with salt marsh environments, with the pollen dominated by goosefoot family, grasses, and sedges, with a dryland vegetation of mixed deciduous woodland similar to that recorded in the peat. The diatom assemblage was indicative of brackish marine conditions. The foraminifera and ostracod assemblage were indicative of estuarine conditions, and contained frequent reworked microfossil remains. No clear evidence for human activity was identified within the organic alluvium, although low concentrations of microcharcoal of uncertain origin (i.e., natural or anthropogenic) were present in various samples. On the basis of their preservation and concentrations, no further analysis of diatoms, ostracods or foraminifera is recommended. No further analysis of pollen or plant macroremains is recommended, given the age of the peat deposits. The vegetational history of the Late Mesolithic of the Humber is well studied, and further analysis of peat samples from the Site is unlikely
Keywords	
Funder	Private or public corporation AECOM
HER	North East Lincolnshire HER - unRev - STANDARD
Person Responsible for work	Alex Brown
HER Identifiers	
Archives	Digital Archive - to be deposited with Archaeology Data Service Archive;

Report generated on: 29 May 2024, 10:10



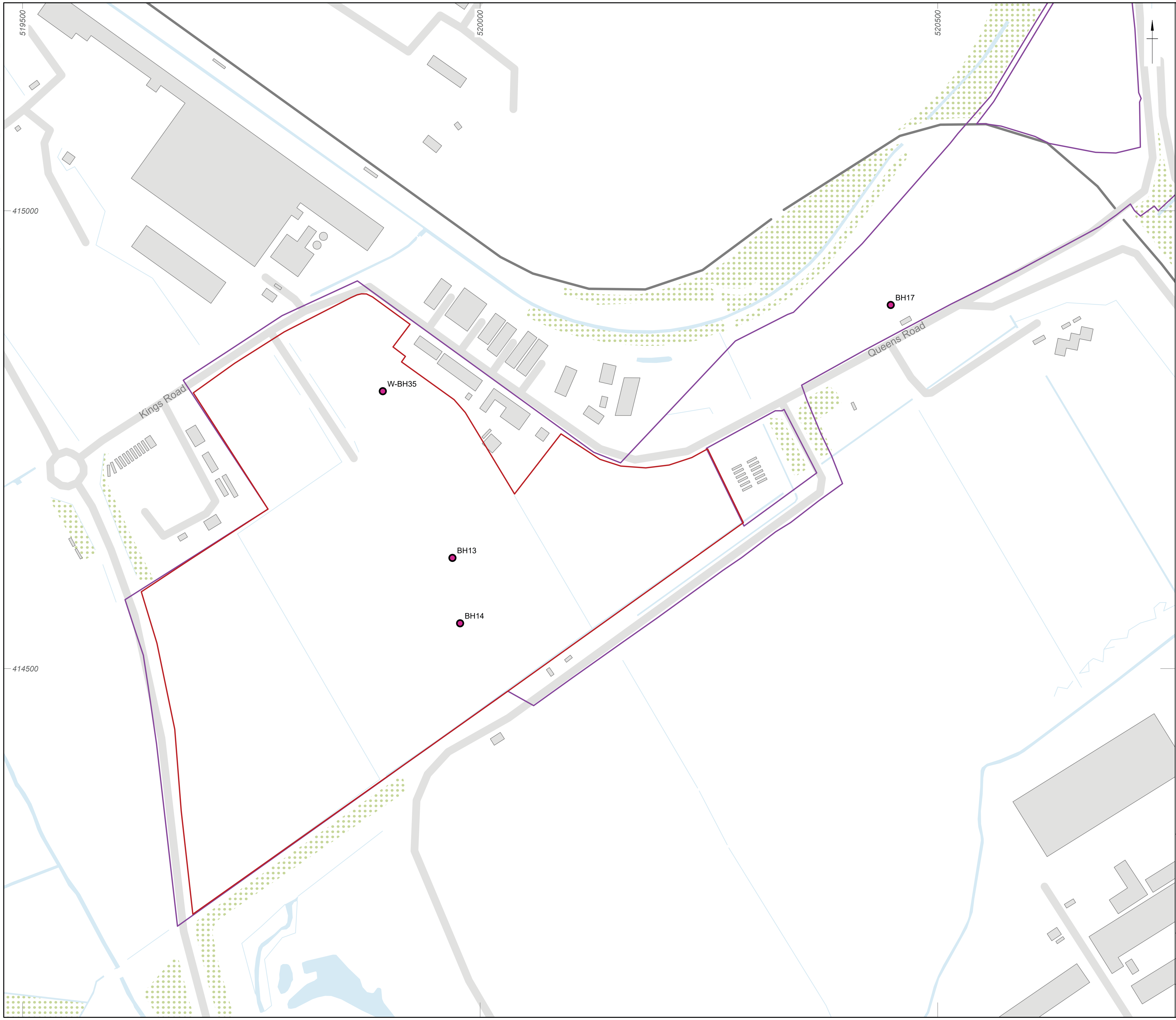
- Site Boundary
- Boundary of Scheme
- Purposive geoarchaeological boreholes
- GI boreholes
- Monitored GI test pits

0 250 m

Coordinate system: OSGB 1936 British National Grid

Date: 28/05/2024	Created by: AW/KJF
Scale: 1:5,000 at A3	Revision: 0

Figure 1: Site location and interventions



Site Boundary

Boundary of Scheme

Boreholes used for palaeoenvironmental assessment

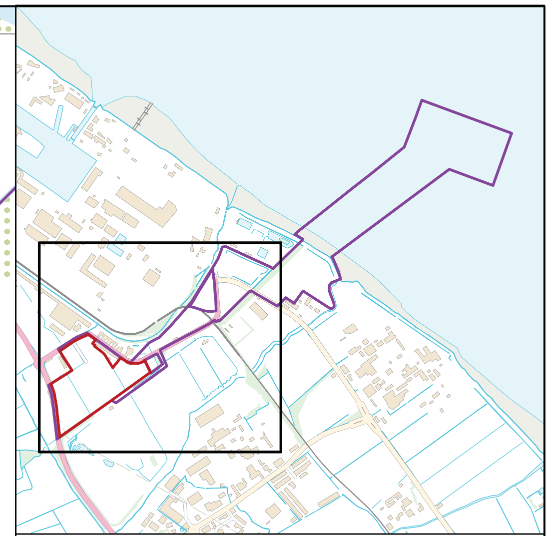
0 100 m

Coordinate system: OSGB 1936 British National Grid

Date: 28/05/2024 Created by: AW/KJF

Scale: 1:4,000 at A3 Revision: 0

Figure 2: Site location and boreholes used for palaeoenvironmental assessment



Site Boundary

Boundary of Scheme

Purposive geoarchaeological boreholes

GI boreholes

Monitored GI test pits

Thickness of Peat

1.40 m

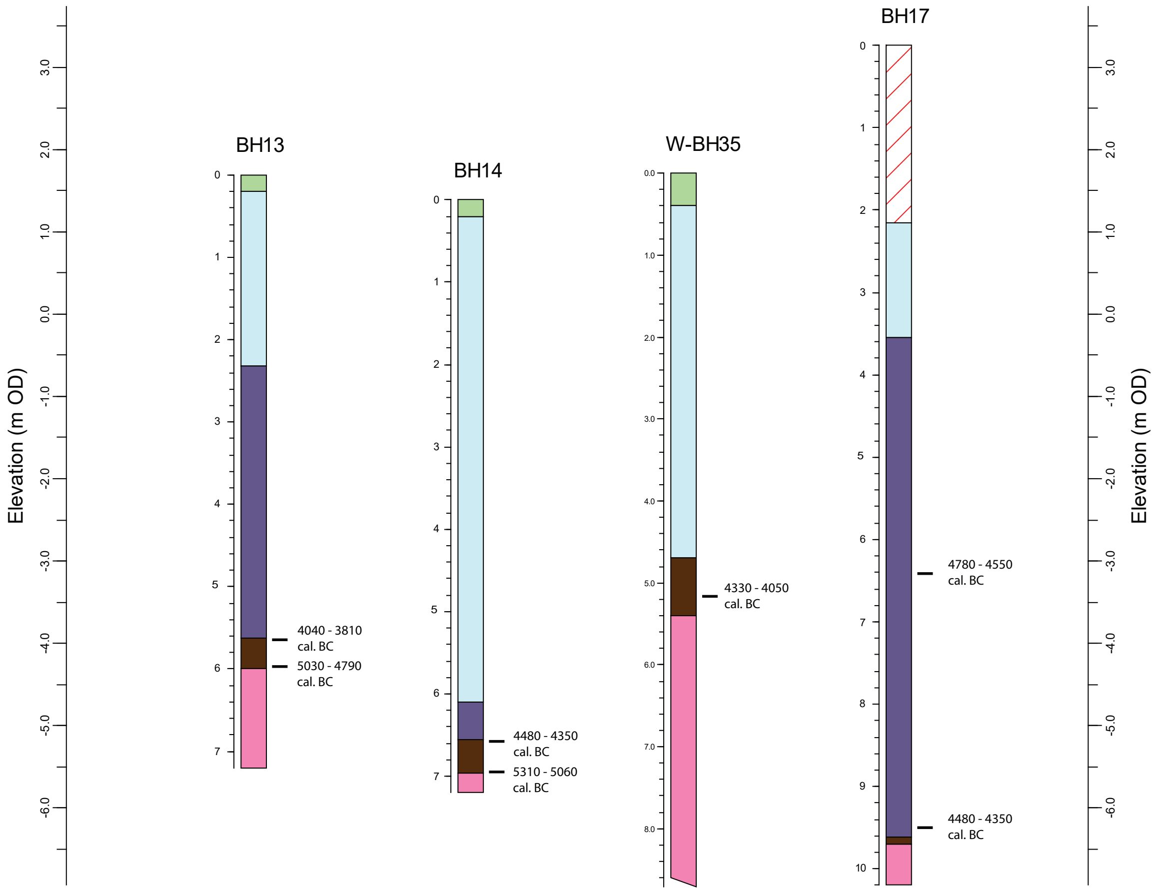
0.10 m

0 200 m

Coordinate system: OSGB 1936 British National Grid

Date: 26/05/2024	Created by: AW/KJF
Scale: 1:5,000 at A3	Revision: 0

Figure 3: Thickness and distribution of peat



Stratigraphy

- Made ground
- Modern soil profile
- Peat
- Alluvium
- Organic alluvium
- Glacial till

Date: 26/05/2024	Created by: KJF	Revision: 0	Scale: Not to scale at A4

Figure 4: Lithology and radiocarbon dates from boreholes BH13, BH14, W-BH35 and BH17

S:\PROJECTS\271004\Graphics_Office\Rep figs\Geoarch\2024_05_06

Wessex Archaeology Ltd registered office Portway House, Old Sarum Park, Salisbury, Wiltshire SP4 6EB
Tel: 01722 326867 Fax: 01722 337562 info@wessexarch.co.uk www.wessexarch.co.uk