# GREENWICH MILLENNIUM VILLAGE
## London SE10

Royal Borough of Greenwich

Geoarchaeological post-excavation assessment and updated project design

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# Greenwich
# London
# SE10

Royal Borough of Greenwich

Site Code: GMP12
National Grid Reference: 540150 179000

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# Executive summary

*This document reports on the results of a geoarchaeological investigation undertaken by Museum of London Archaeology (MOLA) on the site of Greenwich Millennium Village, London SE10. This report has been commissioned from MOLA by Environ on behalf of Taylor Wimpey plc. The centre of the site lies at National Grid reference 540150 179000. The site code is GMP12.*

*Six purposive geoarchaeological boreholes were sunk across the site, revealing a Quaternary sedimentary sequence comprising Pleistocene floodplain gravels overlain by Late Pleistocene to Holocene sediments comprising (Late Pleistocene to Early Holocene bedded alluvial sands, Middle to Late Holocene organic muds and peats and Late Holocene mineral floodplain alluvium capped by modern made ground.*

*In order to explore the palaeoenvironmental potential of the site, subsamples were taken from two boreholes, GA4 and GA6, for radiocarbon dating and pollen, plant macrofossil, ostracod, diatom and insect assessments. These assessments have revealed a series of environmental changes spanning the late Quaternary with particular focus on the palaeoenvironment of the vegetated wetland environments that formed on the site during the Middle and Late Holocene.*

*This assessment has provided an outline of the changing palaeoenvironment throughout much of the Late Quaternary in this part of the Lower Thames valley. Some samples from the site have been shown to have high potential to provide a more detailed picture of these changes. In the light of this assessment, and the geoarchaeological potential of the samples demonstrated in this report, it is recommended that limited further analysis be carried out on selected samples to facilitate subsequent publication of the results.*

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# 1 Introduction

## 1.1 Site background

This document reports on geoarchaeological investigations undertaken at the site of Greenwich Millennium Village, London SE10 and has been commissioned from Museum of London Archaeology (MOLA) by Environ on behalf of Taylor Wimpey plc. The work overall involved the drilling and monitoring of six geoarchaeological boreholes across site. The centre of the site lies at National Grid reference 540150 179000 (Fig 1). The site code is GMP12.

## 1.2 Planning background

The Planning and legislative background to the site is adequately summarised in Section 1.2 of the Written Scheme of Investigation (WSI) prepared for this site (MOLA 2012).

## 1.3 Scope of the works

This report has been commissioned from Museum of London Archaeology (MOLA) by Environ on behalf of Taylor Wimpey plc.

The aim of the present document is therefore to assess the potential of the sediments sampled and recorded within both phases of work with the purpose of reconstructing the site's depositional history and varying past environments as a whole. Thus the conclusions presented in the previous interim reports (MoLAS 2007; MOLA 2013a, 2013b, 2018a) will be updated and refined and, based on their potential and significance, recommendations will be made for further off site analysis work on the samples retained in this assessment document. The significance of the data will be considered in terms of its potential to address archaeological and/or palaeoenvironmentally driven research questions.

## 1.4 Organisation of the report

The principles underlying the concept of post-excavation assessment and updated project design were established by Historic England in The Management of Research Projects in the Historic Environment (MoRPHE). Historic England guidance stresses that the main difference between this and any other report (e.g. an evaluation report), is 'the inclusion of an Updated Project Design, which puts forward proposals for analytical work necessary to bring the site to publication' (Historic England 2015b).

Following this introductory section (Section 1) the document is divided into the following sections:

Section 2 describes the palaeoenvironmental and geoarchaeological background to the site. This places the site into a wider regional context, with particular reference to sites in the immediate area which may be of a contemporary date. Thus the site can be understood in terms of its contribution to the archaeological and palaeoenvironmental record and what further information the data can provide.

The original research aims as outlined in the WSI (MOLA 2012) are stated in Section 3.

Section 4 describes the drilling and recording methods employed for the geoarchaeological borehole survey and the subsequent off site work. The section describes the sampling policy adopted to assess the core samples, listing the number of specialist samples taken from key stratigraphic horizons.

Section 5 presents a synthesis of the specialist assessment work with the stratigraphic data retrieved during the borehole survey. In Section 6 the data recovered is assessed for its potential to answer the original research aims. The information is also considered in terms of further work that may be required, and to determine revised research aims.

Section 7 assesses the information gathered in its wider context. It examines the potential of the site data to answer larger, longer-term, research objectives on both a regional and national scale.

In Section 8 proposals for publication of the results of the work are outlined.

# 2 Palaeoenvironmental and archaeological background

A description of the geological and archaeological background to the site was provided in the earlier geoarchaeological assessment for the site (MoLAS 2007). A resume augmented with the geoarchaeological context of the Lower Thames is provided here.

In brief, the site stratigraphy consists of Tertiary bedrock overlain by fluvial gravels of Late Pleistocene age. Overlying this are Late Pleistocene to Holocene alluvial deposits consisting of in-channel and channel marginal sand deposits, peats and organic muds, and fine-grained floodplain alluvium capped by thick deposits of modern made-up ground. The sequence of natural deposits can be considered within the context of our current understanding of the geological history of the Lower Thames.

### *Tertiary bedrock*

The site is underlain by bedrock strata deposited in the late Palaeocene and early Eocene: the south-eastern parts of the site being underlain by the Thanet Formation (sands and sandstone), the north and west of the site by the somewhat younger deposits of the Lambeth Group (mainly clay, some sands and gravels) (BGS 1998b, 1998a). The bedrock greatly pre–dates the evolution of hominin groups and has no archaeological potential in itself, although its characteristics often determined the nature of succeeding environments and the landscapes occupied and exploited by communities in the past particularly where it outcrops in the lower Thames area.

### *Late Pleistocene gravels*

Throughout the Pleistocene period (the last 2.5 million years), successive cold and warm climatic oscillations have caused alternating downcutting and aggradational cycles to take place along the Thames valley which, together with a background gradual tectonic uplift, has led to a sequence of progressively younger (mainly gravel) deposits down the valley sides. These deposits form a series of river terraces, which represent former floodplains of the river that subsequently became incised and left high and dry as the river down–cut to lower levels (Bridgland 1994).

The present floodplain represents the most recent stage in this sequence. It was created as the river down–cut from a former, higher, floodplain (represented by the Kempton Park Gravels), as a result of the low sea–level and the large influx of meltwater which occurred after the Last Glacial Maximum of the Devensian Glacial period (*c* 18,000 BP). It subsequently deposited coarse grained sediments across the valley floor and these deposits (the Shepperton Gravel) underlie the alluvium in the present floodplain and across the site.

The floodplain gravel was deposited in a network of braided, ephemeral channels at a time when the river had similar characteristics to those flowing in arctic regions today. Within the river, sand and gravel bars accumulated, forming an irregular, undulating surface topography. This gravel aggradation is thought to have ceased between 15ka and 10ka BP (Wilkinson et al 2000; Bates and Whittaker 2004).

Palaeolithic material pre–dating the incision of the present Thames floodplain is occasionally found within or above the floodplain gravels, having been eroded from its place of discard on the higher, older terraces and deposited with the river gravels on the valley floor. Such artefacts are usually rolled and worn and their *ex–situ* context makes them of low interest archaeologically.

### *Holocene sediments*

The alluvial deposits that subsequently masked the gravel topography of the early Mesolithic developed as relative sea level (RSL) rose and estuarine conditions migrated upstream along the Thames throughout the Holocene.

At the Pleistocene/Holocene interface sea level was still very low estimated by Devoy (1982) to have been *c* –30m OD but rising. In the early Holocene a period of low level sea stand meant the Thames valley remained a largely dry, stable land surface, however, as SE England was sinking as a result of isostatic rebound (the earth's crust compensating for the imbalance caused by the weight of ice over northern Britain in the last cold stage), in relative terms, the level of the sea continued to rise with respect to that of the land.

The effect of rising RSL on any location within the floodplain of the Lower Thames Valley during the Holocene was waterlogging of previously dry land surfaces as drainage became ponded-back. Subsequently the onset of increasingly brackish conditions (salt marsh and mudflats) took place in an upstream direction, as estuarine and marine environments migrated progressively upstream.

The rate of isostatic rebound has not been constant and is often masked by the impact of other factors. As a result, RSL rise has not been continuous and has at times appeared to fall, most conspicuously during the Neolithic and Roman periods. In consequence the alluvial sequence is not generally a simple progression from dryland soils to estuarine clays and silts but typically contains interbedded organic silts and peats indicative of hiatuses in this progression (Devoy 1982; Sidell 2003; Bates and Whittaker 2004).

Quaternary scientists and geographers are interested in the alluvial sequence for the information it provides on the pattern of local RSL rise and its implications for Holocene sea level fluctuations and climate change at a wider scale (e.g. Long et al 2000). Archaeologically, however, the significance of the interbedded peats and clays within the floodplain lies in the information they provide about past fluctuations in environment and thus the changing landscape available to be exploited and inhabited by people in the past. The waterlogged conditions of these deposits also preserves evidence for prehistoric activity that rarely survives on dry land sites (e.g. timber structures, wooden artefacts, wattle and matting).

During subsequent periods of marine transgression (inundation) in the area, the landscape would have been a marsh, with numerous small creeks and fleets. Former landscapes have been buried (and protected) beneath the succession of alluvial deposits. Any evidence of early prehistoric activity would be located at the base of the alluvium. Later prehistoric, Roman and medieval activity would be located progressively higher up in the alluvial sequence, with possible medieval and post-medieval activity at the very top of the alluvium.

It is likely that the marshland began to be drained and reclaimed in the medieval period. This initially took the form of drainage channels dug around parcels of land. The purpose of reclamation would have been primarily economic, providing good-quality grazing for livestock and fertile land for crops. The marshland would have been prone to flooding, which would have made it unsuitable for settlement or arable cultivation, but ideal for the formation of improved pasture.

### *Wider modelling of the Lower Thames*

On a broad environmental level, seminal work by Devoy (1977, 1979, 1980, 1982), established a sequence of changes in relative sea level and resulting phases of peat accumulation and mineral sedimentation.

Building on the work of Devoy, a model for the likely impact of rising RSL in the lower Thames has recently been proposed (Bates and Whittaker 2004; Stafford et al 2012). The model proposes a series of Stages (1-6; see Table 2 below) of lower Thames sedimentation and suggests that where the topography of the 'pre-Holocene template' lay below –6m OD it was a wetland area at least by the late Mesolithic; by the early Neolithic land around –2m OD was inundated; and by the late Neolithic to early Bronze Age surfaces below 0m OD were inundated (Stafford et al 2012, 8.7). Such wetland expansion caused islands of higher land to be created, as the surrounding lower-lying land turned to marsh and mudflats. These islands may have become targeted for exploitation and are often associated with evidence for prehistoric activity. Finally, during the late prehistoric and historic periods submergence of the floodplain occurs depositing essentially minerogenic sediments up to the level that underlies modern made ground today.

Table 1 Stages of Lower Thames deposition (Bates and Whittaker 2004)

| Stage | Time period | Characteristics |
|---|---|---|
| 1<br>Late Glacial | (1a) 30-15ka BP | Late glacial period; low sea level; reworking of river terraces under periglacial conditions; downcutting by river greatest at Glacial Maximum (height of cold period) 18ka BP. |
| | (1b) 15ka-10kaBP | Valley infilling and deposition of Shepperton gravels; late glacial braided channel system; high fluvial energy. |
| 2<br>Early Holocene | 10 – 6/7ka BP | Early Period of landscape stability across floodplain; low fluvial energy; complex vegetation mosaics; sedimentation largely sand bodies within river channels and areas of localised peat growth. Mesolithic and early Neolithic occupation. |
| 3<br>Middle Holocene | 6/7 - 5 ka BP | Major landscape instability; sea level rise associated with extensive flooding (initially freshwater then brackish); expansion of wetland environments across previously dryland areas; mainly minerogenic sedimentation (clay/silts); numerous temporary and ephemeral land surfaces existing within flooded zone. Neolithic period. |
| 4<br>Late Holocene | 5 - 3ka BP | Apparent sea level fall and associated reduction of tidal influence; period of organic sedimentation under brackish conditions (Alder carr peat development) equating with Devoy's Tilbury III; expansion of wetland environments inland; topographic variation lost. Neolithic / Bronze Age. |
| 5<br>Later Holocene | 3-1ka BP | Final submergence of floodplain with minerogenic (clay/silt) sedimentation dominating; no organic sedimentation; brackish tidal conditions as tidal head moves up lower Thames. Late Bronze Age; Iron Age; Roman; early medieval periods. |
| 6<br>Later Holocene | 1ka BP - present | Human manipulation of floodplain (flood defences and drainage channels); sedimentation rates reduce. Medieval post-medieval periods. |

# 3 Original research aims

All research questions were devised in accordance with the priorities established in the Museum of London's (2002) *A research framework for London Archaeology*. These were also guided by the recommendations outlined in the Historic England guidelines for Environmental Archaeology and Geoarchaeology (2011, 2015a). The original research questions (ORAs) were first presented in the previous WSI (MOLA 2012, 2.2), and were divided into a series of broad research questions followed by specific research aims based on the results of previous geoarchaeological modelling (MoLAS 2007).

Broad research questions:

- Are deposit sequences of palaeoenvironmental/geoarchaeological interest present on the site?
- What is the potential of these deposits to reconstruct past landscapes?
- Can the deposit sequences be assigned to a chronological framework?
- Is there evidence of dryland soil horizons, which may contain evidence of human occupation, present within the deposit sequence?
- What is the level of modern truncation across the site?

More specific aims, based upon the geoarchaeological modelling of the site, are to:

- Establish the date and environment represented by the basal sands and sandy silts (Facies 2, as defined in this report), and the archaeological/palaeoenvironmental potential of these deposits;
- Establish whether any evidence for landscape stability, a hiatus in deposition, or soil formation exists at the surface of the gravel (Facies 1) and/or the basal sands (Facies 2), and the potential for any such land surfaces for evidence of prehistoric activity;
- Establish the date of peat (Facies 3) development across the site and whether it was diachronous, as well as the environments represented by the peats and their archaeological/palaeoenvironmental significance;
- Establish the environment of deposition of the alluvial clays (Facies 4), whether they are truncated, and whether evidence for the pre-industrial land surface survives;
- Investigate the date and archaeological/environmental significance of any channels crossing the site.

# 4 Methodology

## 4.1 On site

Teams from Geotechnical Engineering Limited drilled 6 boreholes with a Comacchio rig fitted with a windowless core sampler (see Photograph 1), under the supervision of MOLA Geoarchaeologists. The boreholes were drilled to the surface of the Pleistocene sand and gravel deposits or underlying geology in accordance with the WSI (MOLA 2012).


Photograph 1 Drilling rig in positon at GA6

The core columns were drilled through the Holocene sequence and sediments recovered in 1.5m long plastic tubes (see Photograph 2). The deposits were preliminarily logged before being labelled and sealed and transported back to the MOLA geoarchaeological laboratory. The deposits were described using standard sedimentary criteria (relating to colour, compaction, texture, structure, bedding, inclusions, and clast-size).

Photograph 2 Labelled and sealed cores

MOLA surveyors recorded the location of the boreholes to the OS grid, with m OD obtained for the top of the boreholes. The locations of the boreholes are illustrated in Fig 2.

## 4.2 Off site

The following procedures were carried out on each core sample as appropriate.

### *Sediments (section 5.1)*

All the core samples were split, cleaned and described, using standard sedimentary criteria, as outlined in Jones et al (1999). This attempts to characterise the visible properties of each deposit, in particular relating to its colour, compaction, texture, structure, bedding, inclusions, clast-size and dip. For each profile the depth and nature of the contacts between adjacent distinct units was noted.

Furthermore, the borehole cores (and others from BGS open source data plus those from previous geoarchaeological work in the area) were logged in table format and entered into a digital database (Rockworks), which was used to compare and correlate the stratigraphy across the site. Cross-sections were drawn through the data points and correlations were made between key deposits which were then interpreted into facies (a series of site-wide deposits which are representative of certain environments), these cross-sections are shown in Fig 3, Fig 4 and Fig 5.

The Rockworks data was then transferred to an Arc GIS v.10 programme through which the topographic plot of the Early Holocene surface was created. This gives an approximation of the topography of the site as it existed at the beginning of the Holocene period (i.e. the early Mesolithic, *c* 10 000 years ago) and its development over time. The modelled elevation of the early Holocene surface is shown in Fig 6, and this in turn was used to define area of differing palaeoenvironmental and archaeological potentials ('landscape zones') shown in Fig 9.

### *Dating (section 5.3)*

Sub-samples of organic material were taken from the top and bottom of the organic strata in GA4 and GA6 in order to extract plant macrofossils for Accelerator Mass Spectrometry (AMS) $^{14}C$ (radiocarbon) dating. The AMS $^{14}C$ dating was carried out by Beta Analytic, Florida, USA, and are quoted in Table 5 in accordance with international standards (Stuiver and Kra 1986).

### *Ecological Remains (sections 5.4, 5.5, 5.6, 5.7, and 5.8)*

Natural deposits surviving within the cores from GA4 and GA6 were sub-sampled (illustrated in Photograph 3, see also section 5.2 and Table 5) for microfossil (pollen, diatom and ostracod) remains which were submitted to external specialists for assessment, in order to identify the preservation quality, range and abundance of environmental remains and their potential for past environment reconstruction. Larger sub-samples taken from organic strata in both boreholes were processed for plant macrofossil assessment at MOLA and for insect remains at Canterbury Archaeological Trust. Results of these assessments are given in Table 10 to Table 17, inclusive.

Photograph 3 Laboratory subsampling of GA6

### *Synthesis of Results (section 5.9)*

The results of the different types of assessment outlined above have been drawn together in this geoarchaeological assessment report. This has produced an outline of the development of the site and an assessment of its potential for further archaeological and palaeoenvironmental investigation.

# 5 Results of the assessment

## 5.1 Lithostratigraphy

### *Introduction*

The assessment in total comprised of six boreholes (GA1 – GA6) which were designed to both characterise the stratigraphy and to assess the nature of the palaeoenvironmental indicators. The results of the lithostratigraphic survey at the site were reported in the previous interim reports (MOLA 2013a, 2013b, 2018a), and are summarised below. The primary objective of the assessment was to analyse the sediments to assess the quality and potential of any surviving geoarchaeological deposits or remains across the site. The deposit sequence in each borehole is described and the results are presented below. All the boreholes are shown in the transects (Fig 3, Fig 4, and Fig 6) with their locations illustrated in Fig 2. In order to facilitate their description and subsequent assessment and discussion, the sediments have been grouped into 'facies' or sediment types which reflect different depositional environments.

### *Results*

GA1 was situated in the north of the site. It was drilled from the ground surface (6.38m OD) to a depth of 10.5m below ground level (bgl) (-4.12m OD).

Table 2 GA1 log

| **GA1** | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540168 Northing: 179193 Elevation: 6.38m OD | | | | | | |
| Top (m bgl) | Base (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.4 | 6.38 | 5.98 | 0.4 | Moderately firm grey brown plastic very sandy clay with occasional gravel | Facies 5 - Made ground (Late Holocene / modern) |
| 0.4 | 0.8 | 5.98 | 5.58 | 0.4 | Moderately firm grey brown plastic very sandy clay with occasional CBM, brick, wood and frequent gravel | |
| 0.8 | 1.6 | 5.58 | 4.78 | 0.8 | Concrete slab/crushed concrete | |
| 1.6 | 1.8 | 4.78 | 4.58 | 0.2 | Firm mid to dark grey silty clay | |
| 1.8 | 2.3 | 4.58 | 4.08 | 0.5 | Firm black odorous silty clay (diesel contamination) | |
| 2.3 | 2.5 | 4.08 | 3.88 | 0.2 | Firm mid brownish grey silty clay with rare flint | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **GA1** | | | | | | |
| 2.5 | 5.85 | 3.88 | 0.53 | 3.35 | Moderately firm mid brownish grey often patchily very dark grey to black (not odorous) silty clay with chalk from 2.5m to 4m bgl (frequent/cluster of frags at 3.7m to 4m bgl), rare granular brick (3.3m bgl) clinker/coal (4.7m bgl), occasional modern/19th Cent wood fragments; occasional rounded flint throughout; horizontal contact at base | Facies 4 - Floodplain alluvium (Late Holocene / historic) |
| 5.85 | 7.2 | 0.53 | -0.82 | 1.35 | Firm mid brownish grey silty clay slightly oxidised, blocky at top 0.5m with fine rootlets becoming plastic with depth by 7m bgl becoming slightly organic at base; graded contact. | |
| 7.2 | 7.3 | -0.82 | -0.92 | 0.1 | Firm dark reddish grey brown silty clay with frequent peat fragments throughout | Facies 3 - Alder carr wetland (Middle-Late Holocene / late prehistoric) |
| 7.3 | 7.8 | -0.92 | -1.42 | 0.5 | Firm dark reddish brown peat fibrous and woody with silty clay element | |
| 7.8 | 8.2 | -1.42 | -1.82 | 0.4 | Firm mid grey silty clay with bands of moderately frequent peaty organics throughout with wood at 7.9m bgl. | |
| 8.2 | 8.4 | -1.82 | -2.02 | 0.2 | Firm dark brown organic clay with peaty organics and wood fragments occasionally throughout | |
| 8.4 | 9 | -2.02 | -2.62 | 0.6 | Soft dark brownish grey becoming mid grey fine sands | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |
| 9 | 10 | -2.62 | -3.62 | 1 | Moderately firm light grey, calcareous silty clay with laminations of light grey fine sands toward the top and bottom 0.2m. | |

| GA1 | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 10.5+ | -3.62 | Not bottomed | | Greenish grey coarse sands and fine to medium sub angular flint clasts. | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |

GA2 was situated in the central part of the site. It was drilled from the ground surface (6.34m OD) to a depth of 11.6m bgl (-5.26m OD).

Table 3 GA2 log

| GA2 | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540195 Northing: 179086 Elevation: 6.34m OD | | | | | | |
| Top (m bgl) | Base (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.4 | 6.34 | 5.94 | 0.4 | Moderately firm grey brown plastic very sandy clay with occasional gravel | Facies 5 - Made ground (Late Holocene / modern) |
| 0.4 | 1.55 | 5.94 | 4.79 | 1.15 | Moderately firm grey brown plastic very sandy clay with occasional CBM, brick, wood and frequent gravel | |
| 1.55 | 5 | 4.79 | 1.34 | 3.45 | Stiff blocky mid grey brown clay silt with black staining (non-odorous, associated sometimes with coal fragments) with occasional sub rounded gravel from 2.5m bgl and chalk fragments and clay pipe (3m bgl) | |
| 5 | 6.45 | 1.34 | -0.11 | 1.45 | Plastic mid grey brown silty clay occasionally very dark grey with single large charcoal fragment (5.7m bgl) and fine to medium fragments of brick (6m-6.25m bgl) where the silty clay becomes more blocky | |
| 6.45 | 6.5 | -0.11 | -0.16 | 0.05 | Dark grey brown blocky organic silty clay | Facies 4 - Floodplain alluvium (Late Holocene / historic) |
| 6.5 | 7.6 | -0.16 | -1.26 | 1.1 | Very stiff mid brown partially oxidised clay with fine white tread-like veins ($CaCO_3$ leaching) | |
| 7.6 | 9 | -1.26 | -2.66 | 1.4 | Very dark reddish brown woody humified peat | Facies 3 - Alder carr wetland (Middle-Late Holocene / late prehistoric) |

| GA2 | | | | | | |
|---|---|---|---|---|---|---|
| 9 | 9.5 | -2.66 | -3.16 | 0.5 | Dark grey soft fine sandy clay | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |
| 9.5 | 11.3 | -3.16 | -4.96 | 1.8 | Moderately firm dark greenish grey becoming lighter olive green from 10m bgl laminated with occasional clay bands (9.6m,9.75m,9.9m & 10m bgl) and calcareous clays between 10.75m and 11m bgl as well as organics at 10.4m bgl | |
| 11.3 | 11.6+ | -4.96 | Not bottomed | | Greenish grey coarse sands and fine to medium sub angular flint clasts. | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |

GA3 was situated in the central part of the site. It was drilled from the ground surface (6.9m OD) to a depth of 12.5m bgl (-5.6m OD).

Table 4 GA3 log

| GA3 | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540137 Northing: 179023.8 Elevation: 6.9m OD | | | | | | |
| Top (m bgl) | Base (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.2 | 6.9 | 6.7 | 0.2 | Tarmac. Clear horizontal contact with below. | Facies 5 - Made ground (Late Holocene / modern) |
| 0.2 | 0.6 | 6.7 | 6.3 | 0.4 | Firm light brown stony sandy clay with frequent brick and concrete fragments. Clear horizontal contact with below. | |
| 0.6 | 1.7 | 6.3 | 5.2 | 1.1 | Firm dark grey sandy clay with moderately frequent stones, frequent brick and concrete fragments, and occasional slate. Clear horizontal contact with below. | |
| 1.7 | 1.95 | 5.2 | 4.95 | 0.25 | Loose, predominantly pink, brick and hardcore rubble. Clear horizontal contact with below. | |
| 1.95 | 2 | 4.95 | 4.9 | 0.05 | Black ashy loam with moderately frequent stones. Clear horizontal | |

| GA3 | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | contact with below. | |
| 2 | 3.05 | 4.9 | 3.85 | 1.05 | Loose light brown gravel with sand and brick. Clear horizontal contact with below. | |
| 3.05 | 3.4 | 3.85 | 3.5 | 0.35 | Soft mid brownish grey silty clay. Graded contact with below. | |
| 3.4 | 4.2 | 3.5 | 2.7 | 0.8 | Soft black silty clay with fragments of black glassy clinker. Graded contact with below. | |
| 4.2 | 5.5 | 2.7 | 1.4 | 1.3 | Soft dark grey clean silty clay. Graded contact with below. | Facies 4 - Floodplain alluvium (Late Holocene / historic) |
| 5.5 | 6.9 | 1.4 | 0 | 1.4 | Soft brownish grey slightly organic silty clay. Graded contact with below. | |
| 6.9 | 8 | 0 | -1.1 | 1.1 | Moderately firm light greenish grey plastic silty clay with calcareous nodules. Graded contact with below. | |
| 8 | 9.45 | -1.1 | -2.55 | 1.45 | Moderately firm grey plastic silty clay with organic (eroded peat) fragments. Clear and uneven contact with below. | Facies 3 - Alder carr wetland (Middle-Late Holocene / late prehistoric) |
| 9.45 | 10.6 | -2.55 | -3.7 | 1.15 | Dark brown clayey woody peat becoming more woody from 10m bgl and with occasional fine to medium sand lenses towards the base of the unit. Clear horizontal contact with below. | |
| 10.6 | 10.8 | -3.7 | -3.9 | 0.2 | Soft brownish grey slightly organic silty clay with occasional fine to medium sand lenses throughout. Graded contact with below. | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |

| | | | | | | |
|---|---|---|---|---|---|---|
| **GA3** | | | | | | |
| 10.8 | 11 | -3.9 | -4.1 | 0.2 | Soft greenish grey plastic silty clay with occasional sand lenses and gravel and calcareous element. Clear horizontal contact with below. | |
| 11 | 12 | -4.1 | -5.1 | 1 | Dense olive green medium sand. Clear and horizontal contact with below. | |
| 12 | 12.5+ | -5.1 | Not bottomed | | Olive green sands and gravels, clast supported, granule to pebble sized flints. | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |

GA4 was situated in the central part of the site. It was drilled from the ground surface (5.38m OD) to a depth of 10m bgl (-4.62m OD).

Table 5 GA4 log

| **GA4** | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540175, Northing: 178947 Elevation: 5.38m OD | | | | | | |
| Top (m bgl) | Base (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.8 | 5.38 | 4.58 | 0.8 | Mid brownish grey sandy very gravelly silt/clay with red brick cobbles and concrete fragments. | Facies 5 - Made ground (Late Holocene / modern) |
| 0.8 | 1.04 | 4.58 | 4.34 | 0.24 | Pale orange grey silt/clay with charcoal/ash flecks | |
| 1.04 | 1.5 | 4.34 | 3.88 | 0.46 | Dark greenish grey firm sandy silt/clay with granules of chalk, concrete and brick, decaying wood fragments and a scrap of orange netlon. | |
| 1.5 | 2.07 | 3.88 | 3.31 | 0.57 | Loose grey brown sandy brick and concrete gravel | |
| 2.07 | 2.25 | 3.31 | 3.13 | 0.18 | Pale greenish grey mottled dark green/brown silt/clay | |
| 2.25 | 2.38 | 3.13 | 3 | 0.13 | Very dark grey wet clayey angular gravel (flint, brick, concrete). Diffuse to: | |
| 2.38 | 3.88 | 3 | 1.5 | 1.5 | Dark grey, with very frequent bluish black mottles, firm and slightly crumbly/soil-like texture, organic and slightly fibrous silt/clay, with fine rootlets. Diffuse to: | |
| 3.88 | 5.08 | 1.5 | 0.3 | 1.2 | Very dark grey, almost bluish black, humic silt/clay with rare chalk granules. Sharp to: | Facies 4 - Floodplain alluvium (Late Holocene / historic) |
| 5.08 | 5.23 | 0.3 | 0.15 | 0.15 | Dark brownish grey slightly fibrous organic silt/clay. Grading into: | |
| 5.23 | 6.15 | 0.15 | -0.77 | 0.92 | Pale bluish grey silt/clay with rare weak calcareous granules ('race'). Grading into: | |

| GA4 | | | | | | |
|---|---|---|---|---|---|---|
| 6.15 | 6.4 | -0.77 | -1.02 | 0.25 | Dark grey mottled brown, organic silt/clay with woody plant remains. Diffuse to: | Facies 3 - Alder carr wetland (Middle-Late Holocene / late prehistoric) |
| 6.4 | 7.8 | -1.02 | -2.42 | 1.4 | Dark brown silty humified wood peat with frequent large horizontal roundwoods. | |
| 7.8 | 9.66 | -2.42 | -4.28 | 1.86 | Olive green silty sand. | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |
| 9.66 | 10+ | -4.28 | Not bottomed | | Grey, very coarse sandy flint gravel. Gravel is subrounded to subangular pebbles and granules of flint. End BH | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |

GA5 was situated in the south of the site. It was drilled from the ground surface (4.58m OD) to a depth of 11.5m bgl (-6.92m OD).

Table 6 GA5 log

| GA5 | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540064 Northing: 178883 Elevation: 4.58m OD | | | | | | |
| From (m bgl) | To (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.53 | 4.58 | 4.05 | 0.53 | Turf over mid grey, locally stained blue, sandy silt/clay with roots, brick and concrete pebbles and cobbles. Diffuse to: | Facies 5 - Made ground (Late Holocene / modern) |
| 0.53 | 0.75 | 4.05 | 3.83 | 0.22 | Multi-coloured sandy clayey gravel. Gravel is angular pebbles and cobbles of yellow and red brick and shattered flints. Diffuse to: | |
| 0.75 | 1.02 | 3.83 | 3.56 | 0.27 | Mid grey brown silt/clay with granules of red brick, flint, coal and mortar. Rare red brick cobble. Diffuse to: | |
| 1.02 | 1.14 | 3.56 | 3.44 | 0.12 | Black sandy silt/clay with decaying wood fragments and strong hydrocarbon | |

| GA5 | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | odour. | |
| 1.14 | 1.7 | 3.44 | 2.88 | 0.56 | Very dark greyish brown firm sandy gravelly silt/clay with shattered flint, red and yellow brick pebbles, granules of concrete, and fragments of decaying wood. Diffuse to: | |
| 1.7 | 2.3 | 2.88 | 2.28 | 0.6 | Pale grey brown, locally orange brown, silt/clay with occasional subrounded to subangular flint, brick and concrete granules and pebbles. Sharp to: | |
| 2.3 | 4.4 | 2.28 | 0.18 | 2.1 | Black, friable to loose slightly wet gravel of clinker, ash, some flint and red brick fragments. Rare whole red bricks. Becoming clayey below 3.00m bgl. Fragment of red tile at 3.65m bgl. Diffuse to: | |
| 4.4 | 4.5 | 0.18 | 0.08 | 0.1 | Mid grey brown sandy silt/clay with subangular flint pebbles. | |
| 4.5 | 4.75 | 0.08 | -0.17 | 0.25 | Black, friable to loose slightly wet gravel of clinker, ash, some flint and red brick fragments. Rare whole red bricks. Becoming clayey below 3.00m bgl. Fragment of red tile at 3.65m bgl. Diffuse to: | |
| 4.75 | 4.9 | -0.17 | -0.32 | 0.15 | Dark brown, locally grey/yellow, sandy gravelly silt/clay. Diffuse to: | |
| 4.9 | 5.05 | -0.32 | -0.47 | 0.15 | Very dark greyish brown slightly organic silt/clay with a single fragment of modern tile. [Possible former soil on floodplain surface?}. Grading into: | Facies 4 - Floodplain alluvium (Late Holocene / historic) |

| | | | | | | |
|---|---|---|---|---|---|---|
| **GA5** | | | | | | |
| 5.05 | 5.6 | -0.47 | -1.02 | 0.55 | Light olive grey silt/clay, with frequent orange brown Fe mottling at 5.20-5.35m bgl. Grading into: | |
| 5.6 | 6.7 | -1.02 | -2.12 | 1.1 | Dark grey silt/clay with very frequent fine rootlets throughout, frequent horizontal wood fragments and roundwoods (granule-pebble size), and rare horizontal reed remains. Diffuse to: | Facies 3 - Marsh and alder carr wetland (Middle-Late Holocene / late prehistoric) |
| 6.7 | 6.84 | -2.12 | -2.26 | 0.14 | Firm mid brownish grey humic silt/clay with decayed woody remains. Diffuse to: | |
| 6.84 | 6.86 | -2.26 | -2.28 | 0.02 | Black humic totally humified peat. Sharp to: (see Photograph 4) | |
| 6.86 | 7 | -2.28 | -2.42 | 0.14 | Pale olive grey, slightly silty medium sand, with thick vertical woody roots. | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |
| 7 | 8.5 | -2.42 | -3.92 | 1.5 | Pale olive grey bedded medium sand. Occasional bands of medium-coarse sand, and thin bands of pale grey silt/clay with some fine organic fibres at 7.93-7.94m, 8.05-8.07m, and 8.19-8.21m. Beds are straight and horizontal, and approximately 50-100mm thick. Vertical woody roots down to ~7.50m bgl. | |
| 8.5 | 10 | -3.92 | -5.42 | 1.5 | Olive grey medium-coarse sand, becoming coarser with depth, and with faint thick (~100mm) bedding. Band of pale grey silt/clay at 9.13-9.15m. Rare rounded flint pebbles. | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **GA5** | | | | | | |
| 10 | 11.45 | -5.42 | -6.87 | 1.45 | Pale brownish grey coarse sand, locally gravelly sand. Coarsening downwards, becoming very gravelly at base. Gravel consists of subrounded flint pebbles and granules. Grading into: (see Photograph 5) | |
| 11.45 | 11.5+ | -6.87 | Not bottomed | | Very sandy gravel. Sand is coarse and grey-brown in colour. Gravel is subrounded to subangular granules and pebbles of flint, with rare quartz granules and rare greensand pebbles. End BH | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |

Photograph 4 Sharp contact between facies 2 and facies 3 in GA5 at 6.86m bgl

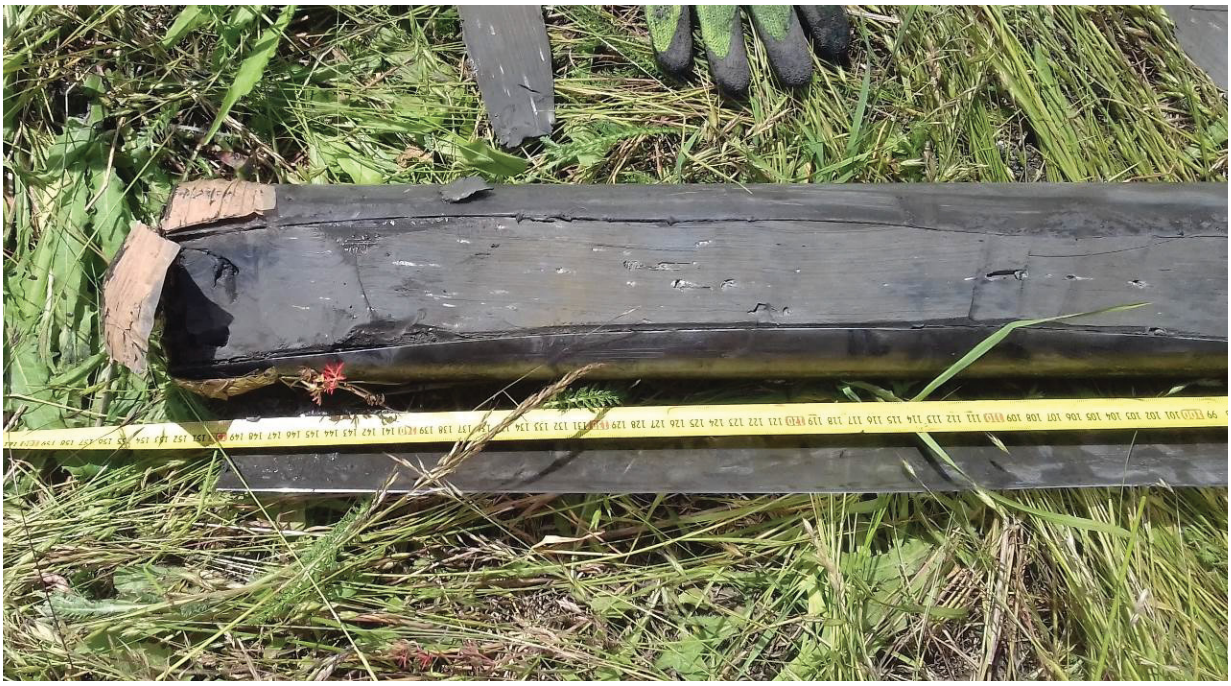
Photograph 5 Top of facies 1 gravels at 11.45m bgl, GA5

GA6 was situated in the south-west of the site. It was drilled from the ground surface (3.59m OD) to a depth of 10m bgl (-6.41m OD).

Table 7 GA6 log

| **GA6** | | | | | | |
|---|---|---|---|---|---|---|
| Easting: 540024 Northing: 178846 Elevation: 3.59m OD | | | | | | |
| From (m bgl) | To (m bgl) | Top (m OD) | Base (m OD) | Thickness (m) | Description | Interpretation |
| 0 | 0.3 | 3.59 | 3.29 | 0.3 | Turf over very firm dark brown clay topsoil. Grading into: | Facies 5 - Made ground (Late Holocene / modern) |
| 0.3 | 0.8 | 3.29 | 2.79 | 0.5 | Stiff mid brownish grey slightly sandy silt/clay with brick, concrete and ash granules, and occasional cobbles of brick and concrete. | |
| 0.8 | 1.7 | 2.79 | 1.89 | 0.9 | Very dark grey, locally dark turquoise blue, firm very sandy and gravelly silt/clay. Gravel is angular granules and pebbles of flint, brick and concrete. | |

| **GA6** | | | | | | |
|---|---|---|---|---|---|---|
| 1.7 | 3.8 | 1.89 | -0.21 | 2.1 | Very dark brownish grey, locally black and pale yellowish grey, loose sandy clayey flint gravel with concrete, brick, mortar and ash granules and pebbles, and some orange brown staining. Strong hydrocarbon odour. Wet below 2.6m. Partially decayed wood at base. Sharp to: | |
| 3.8 | 4 | -0.21 | -0.41 | 0.2 | Dark grey mottled blue-black and green firm silt/clay. Grading into: | Facies 4 - Floodplain alluvium (Late Holocene / historic) |
| 4 | 4.45 | -0.41 | -0.86 | 0.45 | Pale greenish grey firm silt/clay with occasional weak calcareous granules (see Photograph 6). Grading into: | |
| 4.45 | 4.5 | -0.86 | -0.91 | 0.05 | Dark bluish grey mottled black and pale grey, slightly organic silt/clay. | |
| 4.5 | 6.32 | -0.91 | -2.73 | 1.82 | Dark reddish brown wood peat. | Facies 3 - Alder carr wetland (Middle-Late Holocene / late prehistoric) |
| 6.32 | 6.75 | -2.73 | -3.16 | 0.43 | Pale olive grey firm sandy silt/clay. | Facies 2 - River channel/point bar (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic) |
| 6.75 | 7 | -3.16 | -3.41 | 0.25 | Pale grey silty fine-medium sand. | |
| 7 | 8.45 | -3.41 | -4.86 | 1.45 | Pale brownish grey fine-medium sand, with rare thin bands of grey silt/clay (see Photograph 7). | |
| 8.45 | 8.5 | -4.86 | -4.91 | 0.05 | Band of pale green grey clayey silty fine sand. | |
| 8.5 | 9.3 | -4.91 | -5.71 | 0.8 | Light brownish grey medium-coarse sand. | |
| 9.3 | 10+ | -5.71 | Not bottomed | | Multi-coloured dense coarse sandy poorly sorted gravel of rounded to subangular flint pebbles with rare rounded quartz. End BH | Facies 1 - River braid plain (Devensian / Upper Palaeolithic) |



Photograph 6 Facies 4 sediments c.4.0-4.5m bgl (top to right)

Photograph 7 Silt/clay bands within facies 2 sands at 7.38m bgl in GA6 (top to left)

## 5.2 Subsamples

On the basis of the lithological assessment, the sequences from GA4 and GA6 were selected for further assessment. These boreholes were chosen as they were deemed to be representative of the overall sedimentary sequence at the site and had the best sediment recovery. The subsamples taken from the cores are shown in the table below.

Table 8 Subsamples

| Borehole | Depth (m bgl) | Facies | C14 dating | Pollen | Plant macrofossils | Ostracods | Diatoms | Insects |
|---|---|---|---|---|---|---|---|---|
| GA4 | 8.34-8.36 | 2 | | P1 | | O1 | D1 | |
| GA4 | 8.10-8.12 | | | P2 | | O2 | D2 | |
| GA4 | 7.84-7.86 | | | | | O3 | D3 | |
| GA4 | 7.75-7.80 | 3 | | | | | | |
| GA4 | 7.72-7.74 | | | P3 | | O4 | D4 | |
| GA4 | 7.60-7.70 | | | | | | | I1 |
| GA4 | 7.50-7.60 | | GMP12-GA4-7.50 | | PM1 | | | |
| GA4 | 7.30-7.32 | | | P4 | | | | |
| GA4 | 7.25-7.50 | | | | PM2 | | | |
| GA4 | 7.00-7.25 | | | | PM3 | | | |
| GA4 | 6.95-7.00 | | | | | | | |
| GA4 | 6.82-6.84 | | | P5 | | O5 | D5 | |
| GA4 | 6.75-7.00 | | | | PM4 | | | |
| GA4 | 6.50-6.75 | | | | PM5 | | | |
| GA4 | 6.48-6.50 | | | P6 | | | | |
| GA4 | 6.40-6.50 | | | | | | | I2 |
| GA4 | 6.40-6.45 | | GMP12-GA4-6.40 | | | | | |
| GA4 | 6.26-6.28 | | | P7 | | O6 | D6 | |
| GA4 | 6.22-6.24 | | | | | O7 | D7 | |
| GA4 | 5.88-5.90 | 4 | | P8 | | O8 | D8 | |
| GA6 | 8.83-8.40 | 2 | | | | O9 | D9 | |
| GA6 | 8.00-8.02 | | | P9 | | O10 | D10 | |
| GA6 | 7.38-7.40 | | | | | O11 | D11 | |
| GA6 | 6.34-6.36 | 3 | | P10 | | O12 | D12 | |
| GA6 | 6.18-6.20 | | | P11 | | O13 | D13 | |
| GA6 | 6.02-6.04 | | | | | O14 | D14 | |
| GA6 | 5.84-5.86 | | | P12 | | O15 | D15 | |
| GA6 | 5.76-5.78 | | | P13 | | | | |
| GA6 | 5.38-5.40 | | | P14 | | | | |
| GA6 | 5.35-5.45 | | | | | | | I3 |

| Borehole | Depth (m bgl) | Facies | C14 dating | Pollen | Plant macrofossils | Ostracods | Diatoms | Insects |
|---|---|---|---|---|---|---|---|---|
| GA6 | 5.30-5.50 | | GMP12-GA6-5.30 | | PM6 | | | |
| GA6 | 5.10-5.30 | | | | PM7 | | | |
| GA6 | 5.02-5.04 | | | P15 | | | | |
| GA6 | 5.00-5.10 | | | | | | | I4 |
| GA6 | 4.65-5.10 | | | | PM8 | | | |
| GA6 | 4.58-4.60 | | | P16 | | O16 | D16 | |
| GA6 | 4.55-4.65 | | | | | | | I5 |
| GA6 | 4.50-4.65 | | GMP12-GA6-4.50 | | PM9 | | | |

## 5.3 Radiocarbon chronology

### *Introduction*

After death, living organisms cease carbon exchange with the biosphere and the naturally occurring radioactive isotope of carbon in the organism ($^{14}C$) begins to decay to form the stable element $^{14}N$. Measuring the ratio of the amount of $^{12}C$ to the $^{14}C$ in a sample enables the amount of radioactive decay to be quantified and the age of the death of the organism to be determined.

The radiocarbon determination or conventional radiocarbon age, quoted with a plus or minus error, reflects the number of radiocarbon years before 1950 ('the present' [BP]) based on an assumed constant level of $^{14}C$ in the atmosphere. The radiocarbon determination is sometimes called the raw radiocarbon age to avoid confusion with a true calendar date. The error (e.g. ± 40) represents the statistical uncertainty or 'precision' of the method (a range of 2 relative standard deviations from the mean [2σ]).

Since the level of $^{14}C$ in the atmosphere is known to have varied through time radiocarbon ages need to be 'calibrated' in order to convert them to the calendar timescale; this is done using a 'calibration curve' of records of past atmospheric $^{14}C$. Calibrated ages are expressed as a 95% confidence date range (i.e. there is a 95% confidence that the true calendar age lies within the range) expressed in years 'cal BC' or 'cal AD'. Since the calibration curve is not a straight line and features several 'wiggles' and 'plateaus', a single radiocarbon age may intercept the curve in several places, and therefore return multiple date ranges.

### *Method*

Four samples of organic material were submitted for AMS radiocarbon dating from the facies 3 strata in GA4 and GA6; three of these samples consisted of alder (*Alnus glutinosa*) catkins, and the other sample consisted of the alkali insoluble (humin) organic sediment fraction. The AMS radiocarbon samples were dated by Beta Analytic Inc., Florida, USA. All the dates are conventional radiocarbon ages (Stuiver and Polach 1977) and are quoted in accordance with international standards (Stuiver and Kra 1986). The samples were prepared using an acid-alkali-acid pre-treatment to remove carbonates and extraneous humic acids.

Radiocarbon ages were calibrated to the calendar timescale using OxCal 4.3 (Bronk Ramsey 1995, 2001, 2017), and the internationally agreed calibration curve for the northern hemisphere IntCal13 (Reimer et al 2013). The calibrated date ranges cited in Table 2 are quoted in the form recommended by Mook (1986) and have been calculated according to the maximum intercept method (Stuiver and Reimer 1986).

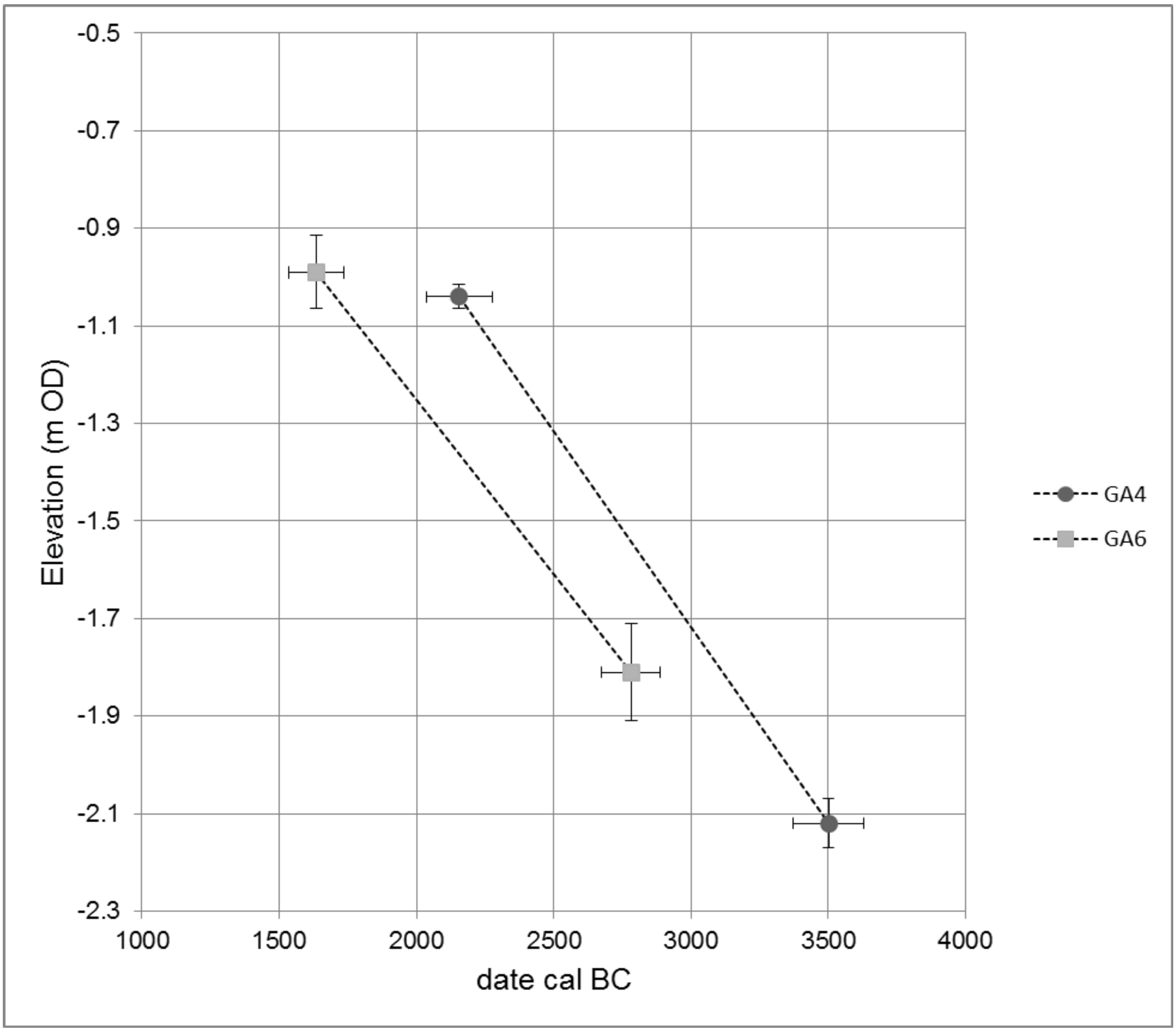
*Results and Discussion*

The results of the radiocarbon dating are presented in the table below.

Table 9 Radiocarbon dates

| Sample | BH | Depth (m bgl) | Midpoint (m OD) | Lab code | Material | $\delta^{13}C$ (‰) (IRMS) | Radiocarbon age (BP) | Calibrated age range |
|---|---|---|---|---|---|---|---|---|
| GMP12-GA4-6.40 | GA4 | 6.40-6.45 | -1.04 | BETA-513310 | Organic sediment (humin) | -28.5 | 3740±30 | 2275-2256 cal BC (3.3% prob.) 2209-2035 cal BC (92.1% prob.) |
| GMP12-GA4-7.50 | GA4 | 7.50-7.60 | -2.12 | BETA-513311 | Alder catkins x2 | -25.8 | 4700±30 | 3629-3584 cal BC (16.3% prob.) 3531-3490 cal BC (21.4% prob.) 3470-3373 cal BC (57.2% prob.) |
| GMP12-GA6-4.50 | GA6 | 4.50-4.65 | -0.99 | BETA-513312 | Alder catkin | -26.5 | 3350±30 | 1736-1716 cal BC (5.3% prob.) 1694-1601 cal BC (76.7% prob.) 1585-1542 cal BC (11.8% prob.) 1539-1534 cal BC (1.1% prob.) |
| GMP12-GA6-5.30 | GA6 | 5.30-5.50 | -1.81 | BETA-513313 | Alder catkin | -27.1 | 4190±30 | 2889-2838 cal BC (23.7% prob.) 2814-2675 cal BC (71.3% prob.) |

The results of the radiocarbon dating have demonstrated that the facies 3 strata at the site date to the Neolithic to Bronze Age periods. The peats began to form towards the end of the Middle Holocene (some time before 3630-3370 cal BC), and appear to have become submerged by the upper alluvium during the Late Holocene (sometime after 1740-1530 cal BC).




Graph 1 Age vs depth plot of radiocarbon dates

Graph 1 shows the radiocarbon dates from both boreholes plotted against elevation, with vertical error bars indicating the vertical sampling interval, and horizontal bars showing the 95% probability calibrated date ranges. Based on this plot, mean peat accumulation rates of 12.5 yr $cm^{-1}$ for GA4 and 14 yr $cm^{-1}$ for GA6 have been calculated. The similarity in mean accumulation rate between both profiles suggests a common driving mechanism that is likely to be closely related to rising trends in RSL during the Holocene. Whilst the broad trend is clear, it is nevertheless not certain that sedimentation would have occurred at an absolutely constant rate throughout this time. Instead sediment accumulation is likely to have fluctuated in response both to fluctuating rates of RSL rise (or even periods of static or falling RSL) and changing sedimentary environments, which may be elucidated both through further dating of the cores and palaeoenvironmental analysis. Although the age depth plots for both sequences are very similar, GA6 appears to be slightly offset (i.e. slightly younger than the dates indicated for comparable elevations in GA4), potentially indicating that peat formation was somewhat time-transgressive across the site, beginning earlier in the north of the site than in the south. Nevertheless, the differences in age between the two profiles at any given elevation might be overstated by the present age depth models since the offset between the profiles is only around 300-400 years, which is barely larger than the uncertainties of the individual radiocarbon dates.

## 5.4 Biostratigraphy: Pollen

Dr Rob Scaife, University of Southampton

### *Introduction*

Samples from two sediment profiles (GA4 and GA6) taken from Millennium Village have been examined for preservation of sub-fossil pollen and fern spores. Recovery of these microfossils would allow reconstruction of the past palaeoenvironments spanning the period of sediment deposition at the site. That is, information on the developing vegetation and environment of the region could be obtained and add to our existing knowledge of the prehistoric and later palaeobiogeography of the Greenwich region. Pollen has been recovered but was found to have very variable preservation, being sparse and in poor condition in some of the samples and absent in the lower alluvial sand and silt seen in both profiles. However, pollen assessment counts have been obtained from the peat and overlying humic alluvium and preliminary pollen diagrams has been constructed from which useful palaeoenvironmental data have been obtained. The results of these analyses are given below.

### *Method*

The two profiles examined are GMP12-GA4 (samples P1-P8) and GMP12-GA6 (samples P9-P16). Standard pollen extraction techniques were used on sediment sub-samples of 1.5ml. volume (Moore and Webb 1978; Moore et al 1991). A sum of up to total 1000 pollen grains coming from dry land plants plus extant marginal and aquatic taxa. Fern spores and miscellaneous palynomorphs were also identified and counted for each sample level. Count numbers were, however, very variable depending upon preservation, which in many cases was poor and as noted, absent in the basal alluvium. This variability is due to the diverse range of sediment types encountered.

These chemical preparation procedures were carried out in the Palaeoecology Laboratory of the School of Geography, University of Southampton and identification and counting was carried out using an Olympus biological microscope at magnifications of x400 and x1000.

Pollen diagrams have been constructed (Fig 7 and Fig 8) using Tilia and Tilia Graph. Percentage calculations used for the sum and sub-groups are as follows.

| | |
|---|---|
| Sum = | % total dry land pollen (tdlp) excluding *Alnus* |
| Marsh/aquatic herbs = | % tdlp + sum of marsh/aquatics including *Alnus* |
| Ferns = | % tdlp + sum of fern spores |
| Misc. = | % tdlp + sum of misc. taxa (pre-Quaternary palynomorphs and other microfossils). |

Because of the high pollen productivity of *Alnus glutinosa* and its autochthonous status, its pollen has been included in the fen/mire category which avoids adverse within sum variations of more terrestrial types (Janssen 1969).

Pollen taxonomy, in general, follows that of Moore and Webb (1978) in some cases modified according to Bennett et al. (1994). These procedures were carried out in the Palaeoecology Laboratory of the Department of Geography and Environment, University of Southampton. An extensive reference/comparative collection of modern pollen types was available for identification of taxa where necessary.

Results

### *GMP12-GA4 (Fig 7)*

Two local pollen assemblage zones (l.p.a.z.) have been recognised between 7.74m and 5.88m bgl. Samples below 7.74m at 8.10-8.12m (P1) and 8.34-8.36m (P2) failed to produce enough pollen of Holocene age to enable pollen counts. Numerous Pre-Quaternary (Eocene, Tertiary) palynomorphs were present in what is believed to be alluvial sediment of uncertain age. The pollen assemblage zones are characterised as follows (Table 6).

Table 10 GA4 pollen assemblage zones

| LPAZ | Palynological character |
|---|---|
| GA4:2<br><br>6.36-5.88m bgl<br><br>*Corylus avellana* type-Poaceae-*Alnus* | This zone is delimited by a sharp decline in Quercus to low levels, the absence of *Tilia* and reduced levels of *Ulmus*. *Fraxinus* is incoming in low values. *Corylus* (47%) along with *Alnus* (75% sum + fen/marsh) have initial peaks. There is a further increase of herb numbers and diversity building on the expansion in the upper zone GA4:1. Dominants include Poaceae (to 46%) Brassicaceae (6%), *Plantago lanceolata* (8%) and Chenopodiaceae (5%). Marsh taxa are dominated by *Alnus* (noted) with a substantial increase in Cyperaceae (to 15%) with remaining fen taxa. Ferns remain important with *Dryopteris* type (to 40%). There is a substantial expansion of pre-Quaternary palynomorphs (to 80% sum + misc.) associated with the mineral sediment. |
| GA4:1<br><br>7.74-6.36m bgl<br><br>*Quercus*-*Tilia*-*Alnus* | *Quercus* (to 70%) with *Tilia* (19%), *Corylus avellana* type (45% at base and declining to *c.*15%) and on-site *Alnus* (72% sum + fen) are the dominant tree taxa. There are small numbers of *Betula*, *Pinus* and a minor peak of *Ulmus* (to 11% at 6.82m). There are few herbs in number or taxonomic diversity. Poaceae are most important and increase from sporadic occurrences in the lower zone to high values at the top (45%). This expansion is accompanied by smaller increases in number and diversity at the top of the zone/transition. These taxa include *Ranunculus* type, Chenopodiaceae and *Plantago lanceolata* especially. Marsh taxa are dominated by *Alnus glutinosa* with increasing values of Cyperaceae (to 9%) with other fen types including *Typha latifolia* and *Typha angustifolia/Sparganium* type and aquatic *Myriophyllum spicatum* (single occurrence). Fern spores are important with high values of monolete *Dryopteris* type at (7.30m; 80% sum + spores). There are small numbers of *Polypodium* throughout and increasing numbers of pre-Quaternary palynomorphs from mid-zone. |

### *GMP-GA6 (Fig 8)*

Three local pollen assemblage zones have been recognised in the sediment profile above 5.90m bgl (Table 7). As with GA4, pollen was largely absent other than pre-Quaternary palynomorphs in the lower alluvium which overlies Pleistocene gravel. That is, at 8.00-8.02m bgl (P9), 6.34-6.36m bgl (p10) and 6.18–6.20m bgl (P11). Pollen was also absent at 5.40-5.38m bgl (P14). In other, organic, samples pollen was largely well preserved but sparse.

Table 11 GA6 pollen assemblage zones

| LPAZ | Palynological character |
|---|---|
| GA6:3<br><br>4.58-4.80m bgl<br><br>Poaceae-*Alnus* | A single level in the upper alluvium. There is a reduction in tree and shrub pollen and an expansion of herbs in numbers and diversity. *Quercus* and *Corylus* remain the principle arboreal taxa. Herbs become dominated by Poaceae (30%) with cereal type present (1%). *Plantago lanceolata* (10%), *Ranunculus* type (5%) and Chenopodiaceae (5%) are present. Fen taxa comprise Cyperaceae, *Typha angustifolia/Sparganium* and *Alisma* type. |
| GA6:2<br><br>4.80-7.75m bgl<br><br>*Quercus*-*Corylus avellana* type- *Alnus* | Arboreal and shrub pollen is dominant with small numbers of herbs. *Quercus* (to58%) and *Alnus* (70% sum + Fen at base) are dominant with *Corylus avellana* type (to 20%). There are small but consistent values of *Betula*, *Pinus*, *Ulmus*, *Tilia*, *Fraxinus* and *Hedera helix*. Herb pollen remains at low levels from GA6:1 with low levels of Poaceae (5%). Fen taxa comprise Cyperaceae (to 9%) with occasional *Typha angustifolia/Sparganium.* Spores of ferns are important with *Dryopteris* type (monolete) to 30% sum + ferns and traces of *Pteridium aquilinum* and *Polypodium vulgare.* |
| GA6:1<br><br>5.75-5.86m bgl<br><br>*Tilia* | This basal zone lies at the top of the basal alluvial sediment and possibly represents the top of a palaeosol. *Tilia* is dominant, both degraded and better preserved (15% and 34% respectively). *Quercus* (25%) and *Corylus avellana* type (18%) are also important. There are few herbs with only Poaceae (5%) and trace of *Plantago lanceolata* present. |

### *Discussion*

As might be expected, both pollen profiles have similarities providing evidence of the changing on and near site palaeoecology and as such, the data can be viewed in terms of the on and off-site vegetation communities. It should also be considered that the taphonomy of the pollen recovered is complicated by variations in the mode of pollen transfer. That is, both airborne and fluvial and other factors of pollen production and dissemination (anemophily and entomophily) may be present in the range of sediment types present.

### *The habitat of deposition*

There are three main phases of sedimentary history and depositional environment represented in these pollen profiles.

Initially, the alluvial lower sediment which is devoid of Holocene pollen was probably a floodplain environment of the Thames which was subject to a fluctuating water table causing oxidation and destruction of the more fragile Holocene pollen. Considerable numbers of reworked, robust, pre-Quaternary, Tertiary palynomorphs are, however, present and are typical of such fluviatile sediment and alluvium. These come from the erosion of older sediment and bedrock, fluvial transport and final deposition. Absence of any Holocene pollen negates any age estimate for this lower sequence. This has been encountered in a number of other studies of Thames floodplain sequences (Scaife 2000b, 2000a) including at Greenwich Peninsular (OGS15) (Scaife 2015).

Pollen preservation starts in the upper levels of this basal alluvium. That is, the basal sample seen in GA6 (l.p.a.z. GA6:1) (P12). As with OGS15 (Scaife 2015), Tilia pollen is present in significantly larger quantities than in the subsequent peat levels. However, this is not considered to be contemporaneous with the sediment and probably represents pollen incorporated into and old land surface/palaeosol which developed on/in the upper alluvial sediment. The pollen at this basal level is poorly preserved and sparse which is consistent with pollen deposition and incorporation into the weathered surface. In this horizon, the on and near site vegetation was probably lime woodland. However, the values of lime (*Tilia*) pollen are over represented because of the robustness of the pollen also giving rise to greater longevity in the sediment and the values of degraded pollen recorded (GA6). Smaller numbers of *Quercus* (oak) and *Corylus avellana* (hazel) are probably under represented here and it is probable that this with oak and probably hazel grew nearby although fluvial transport may also be considered,

Above the transition from the basal mineral sediment to peat and humic sediment, *Alnus glutinosa* (alder) became the dominant on-site vegetation with high percentage values (to >70%) (l.p.a.z. GA4:1 and GA6:2). This was a peat forming, often regarded as semi-terrestrial, community which was highly biologically active during summer and may have been flooded for a maximum of up to three months in winter through overbank flooding. High levels of biological activity were responsible for degradation of the pollen within the peat and resulting low pollen numbers noted by workers since Devoy's seminal work on the lower Thames (Devoy 1979). This was noted at Greenwich Peninsular (Scaife 2015).

This phase of development was floodplain carr woodland with dominant *Alnus glutinosa* possibly with range of other fen wood taxa such *Taxus*, *Frangula*, *Rhamnus*, *Salix* and *Viburnum* seen at other similar sites. This type of alder carr is a clear representation of the environment which became established during the late Mesolithic, middle Holocene which, because of its inhospitable nature, was not influenced to any great extent by human activity. Prehistoric track-ways as at Rainham and Beckton are perhaps the only evidence for penetration of this habitat.

After progressive drying out of this woodland and increasingly poor pollen preservation as a result, the final phase represented was a return to wetter, alluvial conditions from c.2.30m. Alder carr was replaced by wetter grass-sedge fen accompanying a change from peat to a mineral sedimentary regime of humic sediment and finally largely minerogenic alluvium. These upper alluvial levels similarly contain reworked geological palynomorphs from older alluvium.

It can be noted that the area of the pollen catchment will have been extremely local during the phase of peat accumulation but expanding in the upper fen stage through increased openness of the habitat thus allowing ingress of airborne pollen from farther distances and also the possibility of fluvial transport.

The cause of the change to a wetter, herb fen habitat is diagnostic of the late-Bronze Age to early historic period (depending on altitude OD) and was a consequence of regional rising (positive relative eustatic) change. This disrupted the local hydrology through ponding back of the freshwater systems, raising the local ground water table and in many of the Thames floodplain final alluviation with brackish water sediment deposited (Devoy 1979, 1980; Sidell et al 2000; Wilkinson et al 2000). Palynological evidence of this event in this sequence, that is, pollen of halophytes are Chenopodiaceae (goosefoot and oraches) from salt marsh in the top of l.p.a.z. GA4:2 and in zones GA6:1 and through GA6:2.

Because of the change to a more open and fluvial habitat, the pollen catchment became wider. Both of these factors have resulted in a substantial increase of herbs both from the in-situ vegetation and from the surrounding fluvial and airborne pollen catchment.

### *The terrestrial/dry-land zone*

### *Woodland*

The typical dominance of lime woodland (*Tilia cordata*; small leaved lime) during the middle and late Holocene/late prehistoric period is seen in the basal zone (l.p.a.z. GA6:1) with high percentages of fresh (33%) and degraded (15%) pollen. It is suggested that this pollen is within a palaeosol developed in the top of the lower alluvium and is derived from on, or very near site, growth. Lime (*Tilia*) is especially under represented being entomophilous and flowering in summer months when other trees are in full leaf further inhibiting pollen dispersion (Andersen 1970). The importance of lime as dominant or co-dominant (with oak) woodland during the middle Holocene (Mesolithic) and late-prehistoric period (Neolithic and early to middle Bronze Age) has been seen at many other locations in London and southern and eastern England as a whole (Greig 1982, 1989, 1992; Scaife 2000b, 2000a; Crockett et al 2002).

Subsequently, with change to organic/peat accumulation (GA4:1 and GA6:2), the on-site vegetation changed to alder carr woodland. This changed the pollen taphonomy and representation of taxa from the non-mire habitat. Tilia values are at lower levels (up to 19% in GA4:1) but given the under-representation of its pollen, lime was important and probably dominant on better drained soil adjacent to the sample site along with *Quercus* (oak) and *Corylus* (hazel). The small/sporadic values of *Betula* (birch) and *Pinus* (pine) present are attributed to long distance transport from regional and extra regional sources.

The importance of lime and oak/hazel dominated woodland, at least, on site, ended with a change to wetter conditions seen in the upper pollen zones. Lime woodland, however, remained on surrounding drier zones until its demise through human activity during the late Neolithic to middle Bronze Age period. That is, the lime Decline (Turner 1962) and seen at many sites in London and surrounding region (Scaife 2000b, 2000a; Wilkinson et al 2000). Profile GA4 shows the first occurrence of cereal pollen albeit in small numbers from this phase of lime reduction (l.p.a.z. GA4:1 (P5).

### *Herbs*

Contrasting with the dominance of the arboreal and shrub taxa noted in the lower profile, herbs are dominant in the upper, alluvial levels (GA4:2 and GA6:3).

During this later phase, there was less woodland although contrasting with earlier study of Greenwich Peninsular, alder remained locally, probably on the fringes of the floodplain. As noted, however, the changing fluvial conditions significantly altered the pollen taphonomy by extending the pollen catchment. This was also at a time very late-prehistoric or early historic when widespread woodland clearance and changes in land use had occurred.

Thus, apart from the pollen coming from the on-site herb fen, both profiles show grassland, probably pasture, as indicated by a proportion of the high Poaceae (grass) values and additional herbs such as *Plantago lanceolata* (ribwort plantain), *Ranunculus* type (buttercups) and Asteraceae types (Composites). There are, however, also small quantities of cereal pollen in profile suggesting arable cultivation; that is, a mixed agricultural economy.

### *Dating*

There is no palynological indication of the age of the lower alluvium which rests on Devensian river or fluvio-glacial out-wash gravel. The pollen assemblages and inferred vegetation are comparable with other dated Thames floodplain, upper peat sequences and as such a late-prehistoric, late Neolithic-Bronze age date is suggested. Transition to grass-sedge fen, which was ultimately transgressed by alluvium, is attributed to the effects of eustatic change during the very late-prehistoric and early historic period. There is no significant rise in pine or other exotic conifer pollen in the upper levels of these profiles (l.p.a.z. GA4:2 and GA6:3) which indicates that the sediment probably pre-dates planting from c. AD 1650 as an exotic in parks and garden and later for forestry.

### *Summary and Conclusions*

Pollen samples from profiles GA4 and GA6 have been examined for their sub-fossil pollen and spore content with the aim of providing preliminary data on the past vegetation and environment of the site. The study proved successful with some useful information and the following principal findings have been discussed.

- Pollen diagrams have been constructed which show significant changes in the past vegetation and environment. These changes have been described as local pollen assemblage zones.
- Pollen is present in the majority of the sediment but typically absent in the lower alluvial silts except for that in a possible upper soil horizon developed in the top of the silt after a period of drying.
- This possible soil profile (GA6:1) shows the dominance of lime (*Tilia*) woodland probably growing on-site.
- Conditions became wetter allowing the colonisation of the on-site floodplain alder carr woodland.
- During this period (probably late Neolithic and Bronze Age), lime, oak and hazel woodland was important on the interfluves. This was a closed habitat with little evidence of human activity until the end of this phase.
- Sea-level rise during the very late-prehistoric and early historic periods caused increased wetness and waterlogging which resulted in a herb fen community. This was ultimately transgressed with sediment.
- There is some evidence of ephemeral brackish incursion with possible halophytes (Chenopodiaceae) present.
- After a period of woodland clearance, especially the lime, concurrent with the change to more herbaceous fen, the environment was more open; as was the pollen catchment.
- In the upper alluvial levels, there is evidence of grassland, probably pasture but also some cereal cultivation and thus evidence of mixed agriculture.
- Although pollen analysis is not a tool for dating, from the overall chronology seen at other sites along the Thames floodplain, it is suggested that the peat dates to the middle Neolithic at earliest but probably late Neolithic to Bronze Age. Overlying fen and alluvial sediment is suggested as being probably Iron Age and Romano-British. Radiocarbon dating will confirm, or otherwise, these speculations.
- The data presented here bear close similarity with earlier analysis of Greenwich Peninsular (OGS1) (Scaife 2015) as well as other sites on the Thames floodplain.

## 5.5 Biostratigraphy: Plant macrofossils

Anne Davies, MOLA

### *Methods*

Eight bulk samples were taken from boreholes through humified wood peats (GA4) and floodplain alluvium (GA6). They were processed by flotation using meshes of 0.25mm and 1.00mm to catch the flot and residue respectively, and both flots and residues stored were in water. The flots were scanned briefly, using a low-powered binocular microscope, and the abundance, diversity and general nature of plant macrofossils and any faunal remains were recorded.

### *Results*

Table 8 shows the range and frequency of the biological remains in the samples. Taxonomy follows Stace (1991) which was also used for habitat and ecological data together with Hanf (1983) and Ellenberg (1988). There follows a description of the plant remains by borehole with the presence of other biological remains in the samples also noted.

Table 12 Plant macrofossil results

| **Sample** | **Borehole** | **Depth (m bgl)** | | **Height (m OD)** | | **flot vol (ml)** | **waterlogged plant remains** |
|---|---|---|---|---|---|---|---|
| | | Top | Base | Top | Base | | |
| PM1 | GA4 | 7.50 | 7.60 | -2.12 | -2.22 | 50 | Quite abundant wood & root frags. Occasional seeds of marginal wetland spp. |
| PM2 | GA4 | 7.25 | 7.50 | -7.25 | -7.50 | 20 | Root & wood frags. 3 seeds seen |
| PM3 | GA4 | 7.00 | 7.25 | -7.00 | -7.25 | 40 | Wood & root frags, no seeds seen |
| PM4 | GA4 | 6.75 | 7.00 | -6.75 | -7.00 | 30 | Wood & root frags. Very occ seeds |
| PM5 | GA4 | 6.50 | 6.75 | -6.50 | -6.75 | 10 | wood, occ root, moss. Several seeds of dry and marginal ground. |
| PM6 | GA6 | 5.30 | 5.50 | -1.71 | -1.91 | 80 | Mostly wood, some root frags. 3 *Rubus* seeds |
| PM7 | GA6 | 5.10 | 5.30 | -5.10 | -5.30 | 20 | Wood & root frags, moss. 2 frags Apiaceae seed. |
| PM8 | GA6 | 4.65 | 5.00 | -4.65 | -5.00 | 30 | Wood & root frags. Few *Alnus* catkins & seeds. |
| PM9 | GA6 | 4.50 | 4.65 | -4.50 | -4.65 | 30 | Wood, some root, moss. *Alnus* catkin. Few seeds, mainly dry -ground spp. |

### *GA4*

PM1: The flot was composed largely of wood and root fragments, with very occasional finds of alder (*Alnus glutinosa*) catkins and seeds of marshy places and shallow water, including sedge (*Carex* sp.), fine-leaved water dropwort (Oenanthe cf. aquatica) , crowfoots (Ranunculus subgen. aquaticum) and marshwort (cf. *Apium* sp.).

PM2: Apart from frequent root and wood fragments only two sedge seeds and one of bramble (*Rubus* sp.) were seen in this sample.

PM3: No seeds were preserved in this flot, which consisted entirely of wood and root fragments.

PM4: Once again, very few remains were seen, apart from wood and roots, with only single seeds of bramble, water pepper (*Persicaria hydropiper*) and common chickweed (*Stelleria media*) recorded.

PM5: In addition to the usual wood and roots, a little moss was seen here, and a rather wider range of seeds including elder (*Sambucus nigra*), stinging nettle (*Urtica dioica*) and dock (*Rumex* sp.) as well as the alder, water pepper and sedge seeds found in earlier samples. These new additions are less characteristic of wet conditions and may indicate some drying of the sediments and perhaps an increase in scrubby plants.

### *GA6*

PM6: Three seeds of bramble were the only seeds surviving here, along with relatively large amounts of wood and a single alder catkin.

PM7: Once again preservation of plant remains was very poor apart from the wood and root fragments, with only fragmentary seeds of possible dropwort (cf. *Oenanthe* sp.) seen.

PM8: Occasional alder seeds and catkins were present, as well as wood and a few moss fragments.

PM9: This sample contained a slightly more diverse range of seeds in addition to woody material and occasional moss. The seeds came mainly from plants of relatively dry ground, such as elder, bramble, hazel (*Corylus avellana*), buttercup (*Ranunculus acris bulbosus/repens*) and violet (*Viola* sp.). Only a single alder catkin suggested damp or waterside conditions here.

### *Discussion*

While the identifiable plant assemblages from these samples were very small, and reveal few details about the conditions in which they were deposited, there are hints of environmental changes from the seeds identified. PM1, at the base of the sequence, contains seeds of definite wetland plants, consistent with alder carr or other marshy, shallow-water environments. The three samples above this (PM2, 3 and 4) produced virtually no seeds, perhaps due to periodic drying of the sediments, and that from PM5 seems to confirm this, with only two species (water pepper, sedge and alder) suggestive of damp conditions while a similar number of dry-ground plants were represented.

PM6, 7 and 8 contained few seeds, though remains of alder persisted, but PM9, at the top of the sequence produced only seeds of dry-ground species (apart from alder), with hazel nutshell, elder and bramble seeds suggesting the development of woody scrub.

## 5.6 Biostratigraphy: Ostracods and Foraminifera

Dr John E. Whittaker, Natural History Museum

### *Introduction and methods*

Sixteen subsamples, eight each from two boreholes – GA4 and GA6, were assessed for the presence of ostracods and foraminifera.

Subsamples were weighed and placed in ceramic bowls, having first been broken into small pieces by hand. They were then dried in an oven. After drying a small quantity of sodium carbonate was added (to facilitate the removal of the clay fraction). In each case the sediment mix was immersed in hot water and left to soak for several hours or overnight. It was then washed through a 75 µm sieve with hand-hot water, the resulting residue being returned to the bowl for drying. Because many of the subsamples were very organic this process had to be repeated in order to obtain a satisfactory breakdown. Once thoroughly dry the residue was transferred to plastic labelled bags for storage and picking. For examination, the residue was first sieved through a nest of >500µm, >250µm and >150µm sieves. Sediment from each grade was picked by sprinkling a small amount of residue onto a tray and examining it under a binocular microscope. A representative selection of material from each sample (foraminifera, ostracods - if present- and other sub-fossil material of potential environmental value) was picked out into 3x1" plastic faunal slides and recorded on a presence/absence basis. See accompanying charts (Table 14 and upper panel in Table 15). Detailed recording of any ostracod species was finally undertaken and is presented here as semi-quantitative indications (lower panel in Table 15).

### *Results*

The results of the microfaunal assessments of GA4 and GA6 are presented in the tables below.

Table 13 GA4 microfauna results

| Depth (m bgl) | 5.89 | 6.23 | 6.27 | 6.83 | 7.73 | 7.85 | 8.11 | 8.35 |
|---|---|---|---|---|---|---|---|---|
| Height (m OD) | -0.51 | -0.85 | -0.89 | -1.45 | -2.35 | -2.47 | -2.73 | -2.97 |
| Facies | 4 | 3 | | | | 2 | | |
| Sample | O8 | O7 | O6 | O5 | O4 | O3 | O2 | O1 |
| Weight processed | 60g | 60g | 65g | 65g | 40g | 80g | 75g | 90g |
| **Contained material** | | | | | | | | |
| plant debris and seeds | • | • | • | • | • | • | • | • |
| iron mineral | • | | | | | • | • | |
| earthworm granules | • | | | | | | | |
| algal cysts | • | | • | • | • | | | |
| insect remains | | • | • | | • | | | |
| rhizoliths | | | | | | | | • |
| | | | | | | | | |
| Interpretation | Semi-terrestrial | Wetland | | | | Migrating channel; latterly subject to weathering | | |

• = present

Table 14 GA6 microfauna results

| Depth (m bgl) | 4.59 | 5.85 | 6.03 | 6.19 | 6.35 | 7.39 | 8.01 | 8.39 |
|---|---|---|---|---|---|---|---|---|
| Height (m OD) | -1.00 | -2.26 | -2.44 | -2.60 | -2.76 | -3.80 | -4.42 | -4.80 |
| Facies | 3 | | | | 2 | | | |
| Sample | O16 | O15 | O14 | O13 | O12 | O11 | O10 | O9 |
| Weight processed | 45g | 50g | 60g | 45g | 55g | 75g | 75g | 75g |
| **Contained material** | | | | | | | | |
| plant debris + seeds | • | • | • | • | • | • | | |
| slag | • | | | | | | | |
| rhizoliths/rhizoconcretions | | | | | | • | • | • |
| freshwater ostracods | | | | | | | | • |
| | | | | | | | | |
| **Freshwater ostracods** | | | | | | | | |
| *Candona neglecta* | | | | | | | | x |
| *Candona candida* * | | | | | | | | x |
| *Ilyocypris* spp. | | | | | | | | x |
| *Potamocypris zschokkei* | | | | | | | | x |
| *Limnocythere inopinata* | | | | | | | | x |
| *Limnocytherina sanctipatricii* * | | | | | | | | o |
| *Cyclocypris* sp. | | | | | | | | o |
| | | | | | | | | |
| Interpretation | Wetland | | River alluvium | | | Migrating channel. Initially cold-climate. | | |

Upper panel: • = present

Lower panel: o = single specimen; x = several specimens.

At first glance the results of the microfaunal assessment are disappointing. Only one subsample (O9) contained any ostracods, but the other contained material, as indicated in Table 14 and Table 15, can be used to further a little the environmental interpretation. Due to the organic nature of many of the samples, any calcareous fossils, if they were ever present, would have become decalcified. It is true that in brackish situations, especially salt marsh environments, agglutinating foraminifera will survive preservation in such conditions - they have a test (shell) made up of a thick basal organic template, on which they attach mineral grains with an organic cement. None was found here in spite of a careful search, and it is therefore assumed the sedimentary sequences were probably all deposited in a freshwater environment.

### *GA4*

Eight subsamples (O1 – O8) were examined from GA4, covering a 2.48m long sequence. The results are shown in Table 14.

Facies 2 was represented by samples O1-O3; these sediments were sand with rhizoliths/iron. The significance of the rhizoliths will be discussed further under GA6, below, suffice to say here, the contained material probably indicates a migrating channel (from the evidence of the rhizoliths), latterly subject to weathering (presence of iron mineral).

Facies 3 is represented by subsamples O4-O7 and consists of initially, peats and then organic clays. A few subsamples contained insect remains and small organic spheres of various sizes which may be algal cysts.

The sole subsample from Facies 4 (O8) was a silty clay and contained earthworm granules. The residue from the clay, moreover, was bluish which may indicate gleying (waterlogging), this coupled with iron mineral strongly suggests a semiterrestrial environment, alternatively wet and dry. The earthworm granules, if in situ, would preclude any saline influence.

### *GA6*

A further eight subsamples (O9-O16) were examined from GA6 covering a 3.82m long sequence. The results are shown in Table 15.

Facies 2 was represented by four subsamples (O9-O12), but only O9-O11 contained rhizoconcretions which have important environmental significance here. These subsamples are full of calcareous tubes (externally with sand/silt grains, internally with impressions of stems and rootlets) and concretionary masses. These are what Candy (in Ashton et al 2005, 16) calls, respectively, rhizoliths and rhizoconcretions and they reflect (when associated with a freshwater environment)….“the drying out of the environment and the formation of fully terrestrial conditions either as a result of the initiation of a drier climate….or because of sediment infilling/lateral migrations of the channel system. Rhizoliths, along with other calcrete types, are typically used to indicate the existence of a dry climate, either a semi-arid climate or a humid climate with pronounced dry months”. ….“As rhizoliths may form over relatively short periods of time, i.e. the lifetime of the root, these features may not represent a long-lived period of land surface stability and soil development but could reflect a relatively short-lived land surface”. Furthermore O9 (from 8.38-8.40m below ground level - the lowest examined) contained several species of freshwater ostracods (lower panel, Table 15), also the only subsample examined here to contain ostracods. They probably lived in small water bodies left behind by the migrating channel, but not in the channel itself, but what is really important is that two of the species, marked with an asterisk (*) in Table 15 (*Candona candida* and *Limnocyherina sanctipatricii*) are considered to be cold/cool indicators (fide Whittaker and Horne 2009). Unless reworked, this could indicate that the initial riverine sedimentation above the gravels is Devensian in age. Unfortunately no other ostracods were found in O10 and O11.

## 5.7 Biostratigraphy: Diatoms

Dr Nigel Cameron, UCL

### *Introduction*

Sixteen sediment samples from GMP12 have been prepared and assessed for diatoms. The samples for diatom evaluation were taken from a number of sediment facies in two boreholes (GA4 and GA6) from depths of between 8.36 m to 5.58 m in GA4 and 8.83 m to 4.50 m in GA6. The diatom assessment takes into account 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), Hartley et al. (1996), Krammer & Lange-Bertalot (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 and Discussion*

The results of the diatom evaluation are shown in Table 16.

Diatoms are absent from five samples (D1 to D4, D8) in GA4 and are absent from all eight samples (D9 to D16) assessed from borehole GA6. Small, indeterminate diatom fragments were identified in two samples (D5 and D6). In D5 these remains included a dissolved centric diatom fragment and in D6 a centric diatom fragment and the central raphe nodes of an indeterminate Naviculoid diatom. However, it is not possible to identify the fragments to the species level. Poorly preserved fragments of the benthic, brackish-marine diatom *Nitzschia navicularis* are present in sample D7. This species is common in estuarine mud-surface habitats such as tidal mud flats and creeks.

There is no further potential for further diatom analysis of the sixteen samples assessed from the site. The absence or very poor preservation of diatoms seen in all of the samples assessed is the result of taphonomic processes (Flower 1993; Ryves et al 2001). Diatom silica dissolution and valve breakage is caused by factors such as extremes of sediment alkalinity or acidity, the under-saturation of sediment pore water with dissolved silica, cycles of prolonged drying and rehydration, or physical damage to diatom valves from abrasion or wave action.

Table 15 Diatom results

| Sample | BH | Depth (m bgl) | Height (m OD) | Diatoms present? | Diatom fragments | Preservation | Assemblage type | Potential for % count |
|---|---|---|---|---|---|---|---|---|
| **D1** | GA4 | 5.89 | -0.51 | - | - | - | - | none |
| **D2** | GA4 | 6.23 | -0.85 | - | - | - | - | none |
| **D3** | GA4 | 6.27 | -0.89 | - | - | - | - | none |
| **D4** | GA4 | 6.83 | -1.45 | - | - | - | - | none |
| **D5** | GA4 | 7.73 | -2.35 | - | Yes | Very poor | indet.fragments | none |
| **D6** | GA4 | 7.85 | -2.47 | - | Yes | Very poor | indet.fragments | none |
| **D7** | GA4 | 8.11 | -2.73 | Yes | - | Poor | brackish-marine | none |
| **D8** | GA4 | 8.35 | -2.97 | - | - | - | - | none |
| **D9** | GA6 | 4.59 | -1.00 | - | - | - | - | none |
| **D10** | GA6 | 5.85 | -2.26 | - | - | - | - | none |
| **D11** | GA6 | 6.03 | -2.44 | - | - | - | - | none |
| **D12** | GA6 | 6.19 | -2.60 | - | - | - | - | none |
| **D13** | GA6 | 6.35 | -2.76 | - | - | - | - | none |
| **D14** | GA6 | 7.39 | -3.80 | - | - | - | - | none |
| **D15** | GA6 | 8.01 | -4.42 | - | - | - | - | none |
| **D16** | GA6 | 8.39 | -4.80 | - | - | - | - | none |

### *Conclusions*

- Diatoms were assessed from sixteen samples from two boreholes taken at the Greenwich Millennium Village site.
- Diatoms are absent from thirteen samples. Small, indeterminate diatom fragments were identified in two samples (D5 and D6). Poorly preserved fragments of the benthic, brackish-marine diatom *Nitzschia navicularis* are present in sample D7. This species is common in estuarine mud-surface habitats such as tidal mud flats and creeks.
- There is no further potential for percentage diatom analysis of the samples assessed from Greenwich Millennium Village boreholes GA4 and GA6.

## 5.8 Biostratigraphy: Insects

Dr Enid Allison, Canterbury Archaeological Trust

### *Methods*

Five samples of the facies 3 peats from two boreholes (GA4 and GA6) were submitted to assess the potential of insect remains to provide environmental data.

The five samples were received as raw sediment taken from the borehole cores. Individual sample volumes were 0.25 – 0.9 litres. The samples were gently wet-sieved by hand to 0.3mm and paraffin flotation to extract insect remains was carried out following Kenward et al. (1980).

The paraffin flots were scanned briefly in industrial methylated spirits (IMS) in a petri dish using a low-power stereoscopic zoom microscope (x10 – x45). Identifiable insect remains consisted chiefly of beetles (Coleoptera) and to a lesser extent bugs (Hemiptera). The state of preservation and numbers of individuals and taxa were recorded, and taxa were categorised into broad ecological groups following Kenward et al. (1986) and Kenward (1997). The groups used are shown at the bottom of Table 17. Nomenclature for Coleoptera follows Duff (2018). Other invertebrates were also recorded if present.

### *Results*

Insect remains were noted in all samples. The samples from GA6 were small (0.25 – 0.3 litres) and the limited numbers of insect remains recovered from them reflects this; preservation is moderate to very poor in these samples with most remains highly fragmented which limits the potential for identification. Greater numbers of better preserved insect remains were recovered from the two larger samples from GA4 (0.6 – 0.9 litres).

Remains noted during scanning are described briefly below and details of individual samples are shown in Table 17.

Table 16 Insect results

| BH | Depth (m bgl) | Sample volume | Est MNI beetles and bugs | Preservation | Taxa noted during scanning | Potential for further work |
|---|---|---|---|---|---|---|
| GA6 | 4.55-4.65m | 0.3L | ~20 | Varied preservation; fragmentation high | HEMIPTERA: Pentatomoidea [oa-p], *Cymus* [oa-p], Auchenorhyncha [oa-p], Hemiptera fragments<br>COLEOPTERA: *Agonum* [oa-?d], *Laccobius* [oa-w], *Lesteva* [oa-d], *Phyllopertha horticola* [oa-p], *Prasocuris phellandrii* [oa-p-d]; Coleoptera fragments<br>ARACHNIDA: Acarina (mites) | LOW |
| GA6 | 5.00-5.10m | 0.25L | <5 | Moderate to very poor; high fragmentation | HEMIPTERA: Lygaeidae [oa-p];<br>COLEOPTERA: small unidentifiable fragments | NONE |

| BH | Depth (m bgl) | Sample volume | Est MNI beetles and bugs | Preservation | Taxa noted during scanning | Potential for further work |
|---|---|---|---|---|---|---|
| GA6 | 5.35-5.45m | 0.3L | ~10 | Moderate; some sclerites pale and folded | ANNELIDA: earthworm egg capsules<br>COLEOPTERA: Hyroporinae sp(p) [oa-w], *Cercyon* [u], *Hydraena testacea* [oa-w], *Hydraena* [oa-w], *Contacyphon* [oa-d], Curculionidae [oa-p], Coleoptera sp(p) | LOW |
| GA4 | 6.4-6.5m | 0.6L | 50+ | Good to moderate; much of material is highly fragmented; erosion moderate | HEMIPTERA: Saldidae [oa-d], Delphacidae, Auchenorhyncha spp; Hemiptera fragments<br>COLEOPTERA: Carabidae, *Laccobius* [oa-w], Hydrophilinae sp(p), *Coelostoma orbiculare* [oa-w], Cholevinae [u], *Lesteva* [oa-d], *Cypha* [u], *Falagria* [rt], Aleocharinae spp. [u], *Stenus* [u], *Lathrobium* [u], Staphylininae [u], Elateridae [ob], *Anobium punctatum* or *inexpectatum* [l], *Donacia* [oa-p-d], *Prasocuris phellandrii* [oa-p-d]; Curculionidae [oa-p], Coleoptera spp. fragments<br>HYMENOPTERA: Formicidae (ants), Hymenoptera Parasitica (parasitic wasps)<br>ARACHINIDA: Acarina (mites) | MODERATE |

| BH | Depth (m bgl) | Sample volume | Est MNI beetles and bugs | Preservation | Taxa noted during scanning | Potential for further work |
|---|---|---|---|---|---|---|
| GA4 | 7.6-7.7m | 0.9L | 100+ | Good to moderate; fragmentation less than in the other samples | CRUSTACEA: Daphnia ephippia<br>HEMIPTERA: Pentatomoidea, Lygaeidae, Auchenorhyncha, Psylloidea nymphs<br>COLEOPTERA: *Pterostichus diligens* or *strenuus* [oa], Carabidae spp, *Hydrochus* [oa-w], *Hydrobius fuscipes* [oa-w], *Cercyon tristis* group [oa-d], *Hydraena testacea* [oa-w], *Hydraena* [oa-w], *Limnebius* [oa-w], *Ochthebius* cf *minimus* [oa-w], Silphidae [u], Pselaphinae [u], Aleocharinae spp. [u], *Anotylus* [rt], *Carpelimus* [u], Staphylininae [u], Aphodiinae [ob-rf], *Onthophagus* [oa-rf], *Contacyphon* sp(p), ?*Pomatinus substriatus* [oa-w], Elateridae spp [ob], *Ptinus* [rd, ?Galerucinae [oa-p], ?*Acalles* [l], Scolytinae [l], Curculionidae [oa-p], Coleoptera spp<br>HYMENOPTERA: Hymenoptera Parasitica (parasitic wasps)<br>TRICHOPTERA: trichopteran (caddis) larval head fragments<br>ARACHINIDA: Acarina (mites) | GOOD |
| *Ecological codes for beetles (Coleoptera) and bugs (Hemiptera) are shown in square brackets. Codes are as follows: d – damp ground/waterside, l – wood, oa – 'outdoor' taxa not usually found within buildings or in accumulations of decomposing organic matter, ob – probable outdoor taxa, p – plant-associated taxa; rf – foul decomposers, rt – eurytopic decomposers, u – uncoded, w – aquatics. Some taxa are uncoded pending closer identification* | | | | | | |

### *Sample I1 – GA4 7.6-7.7m bgl*

Insect remains are common and indicative of aquatic and wetland environments and the presence of trees or shrubs. Aquatics include *Hydraena testacea*, typically found in moss and reed litter by standing water or muddy streams (Hansen 1987, 56–61; Duff 2012, 319–20), and ?*Pomatinus substriatus* which is found submerged in lowland streams usually on woody debris, logs or stones (Friday 1988, 149; Godfrey 2003). Trees are indicated by several taxa including a bark beetle (Scolytinae) and a spider beetle (*Ptinus*). Shed nymphal skins of a jumping plant louse are probably *Baopelma foersteri* found on alder (*Alnus*) but this would have to be confirmed by closer examination. Scarabaeid dung beetles (Aphodiinae, *Onthophagus*) typically associated with herbivore dung are also present, suggesting grazing animals in the vicinity. Some of the identifications from this sample are currently tentative and require confirmation which may enhance interpretation.

### *Sample I2 – GA4 6.4-6.5m bgl*

Insect remains are quite common, but somewhat more fragmented than in the previous sample. Remains noted during scanning are chiefly indicative of wetland and emergent and/or waterside vegetation. Aquatic beetles include *Coelostoma orbiculare* a typical fenland species usually associated with mosses, typically in floating rafts of vegetation or at the edges of water bodies (Foster et al 2014). Among plant-associated taxa *Prasocuris phellandrii* is primarily associated with wetland Ranunculaceae (buttercup family) (Cox 2007, 144), while 'reed beetles' (*Donacia*) are found on aquatic and waterside vegetation. There is a hint of dead wood habitats from either *Anobium punctatum* or *inexpectatum*. The first of these species is often associated with structural timber and the second with ivy, but separation of the two species is problematic with fragmentary material.

### *Sample I3 – GA6 5.35-5.45m bgl*

The few identifiable beetles recovered are consistent with a wetland environment. They include *Hydraena testacea* usually associated with moss and litter by standing water or muddy streams, and *Contacyphon* found in well-vegetated environments with shallow pools of standing water.

### *Sample I4 – GA6 5.00-5.10m bgl*

Preservation is particularly poor in this sample and much of the material is reduced to small fragments of eroded cuticle, most of which are probably not identifiable. The only specimen identified during scanning was a fragment of a ground bug (Lygaeidae).

### *Sample I5 – GA6 4.55-4*

The small numbers of beetles noted during scanning were mainly consistent with marshland, including *Prasocuris phellandrii* which is primarily associated with wetland Ranunculaceae (buttercup family). Fragments of *Phyllopertha horticola*, a small chafer whose larvae live and feed at turf roots, suggest the presence of grassland locally.

### *Conclusions and recommendations*

Insect remains from four of the five samples are consistent with a wetland environment. The assemblages with the most potential for further analysis are from GA4 (samples I1 and I2), particularly the lowermost sample taken from a depth of 7.6 – 7.7m bgl. Closer examination of the insect assemblages from these two samples has the potential to provide more detailed information on local environmental conditions and perhaps land use.

## 5.9 Synthesis of the results

This section discusses the deposits in terms of the identified facies, from the oldest to the most recent, integrating the results of the specialist assessments with the recorded sedimentary characteristics. The facies and lithology recorded within the boreholes are illustrated in the transects drawn across the site (Fig 3, Fig 4 and Fig 5). The modelled elevation of the early Holocene surface is shown in Fig 6.

### *Facies 1: Pleistocene gravels (Devensian / Upper Palaeolithic)*

This facies equates with Stage 1b of the Bates and Whittaker (2004) model (Table 1) which results in the formation of the topography of the gravels underlying the site. The gravels underlying the Holocene sediments at the site are the Shepperton gravels laid down during the late Devensian (approximately 15,000-10,000 BP) following a phase of valley incision during the Late Glacial Maximum (Stage 1a).

Within the majority of the site, the Pleistocene gravels show an undulating surface at between c.-2.5 and -6m OD (as shown in Fig 3, Fig 4, Fig 5 and Fig 6).

The Shepperton gravels were laid down in a high-energy fluvial environment. During cold stages of the Pleistocene such as the Devensian, the Thames would have been subject to large seasonal variations in flow regime due to the influx of spring meltwater. During periods of high flow, the river would have occupied multiple shifting channels separated by unstable gravel bars, resulting in the formation of a broad gravel braid plain with an undulating surface. It is this inherited surface topography – the early Holocene surface, modelled in Fig 6 – that would shaped the subsequent fluvial morphology and sedimentary environments during the Holocene. The heights and morphology of the floodplain are important archaeologically as they dictate the nature of the environment and landscape of the Mesolithic as well as influencing the nature and centres of sediment accumulation during and post-dating the Mesolithic particularly in relation to sea-level rise.

### *Facies 2: Lower alluvium (Late Devensian to Early Holocene / Upper Palaeolithic to Mesolithic)*

Facies 2 marks the transition from the Late Devensian to Early Holocene and is equivalent to the transition between Stage 1b and Stage 2 of Bates and Whittaker's (2004) model.

The facies 2 deposits consist of bedded sands and sandy silts, occasionally as in GA5 (Table 6) and GA6 (Table 7), fining-upwards from the underlying gravels (Photograph 5), and with occasional fine bands of silty clay (Photograph 7). These predominantly sandy sediments are typical of formation on the margins of an active river channels in point bars and channel bars, whilst the silty clay bands are indicative of occasional episodes of overbank deposition (Miall 1996).

Palaeoenvironmental indicators from the facies 2 deposits are sparse: three pollen samples (P1, P2 and P9) and six diatom samples (D1-3 and D9-11) were taken from facies 2 deposits, primarily from bands of fine-grained sediment and were all devoid of any pollen or diatoms. Six ostracod samples were taken from the same horizons (O1-3 and O9-11), and ostracods were present in just a single sample (O9). The ostracod fauna in sample O9 shows unambiguously that the facies 2 sediments were formed in a freshwater environment. furthermore, the presence of two species, *Candona candida* and *Limnocytherina sanctipatricii*, shows that facies 2 probably began to form under cold climatic conditions (Whittaker and Horne 2009). This suggests that, although not directly dated, it is likely that facies 2 began to form prior to the rapid warming of the climate at the start of the Early Holocene (Walker et al 2009, 2012).

Although facies 2 deposits occur across the whole of the site (see transects), they do appear to be thicker in areas where the Early Holocene surface (Fig 6) is lower, possibly indicating the course of a former river channel that was active during the Early Holocene, but that appears to have become infilled by the time that facies 3 began to form (see below). The distinction between deeper areas occupied by an active Early Holocene river channel or channels, and areas further away from the channel where the gravel surface was higher, was used to define the two landscape zones (LZs) identified at the site (see

Fig 9). LZ1 would have been occupied by active river channels throughout the entirety of the Early Holocene, and as such in-situ archaeological remains are highly unlikely to exist in this area.

The existence of rhizoliths in the facies 2 sediments (discussed in section 5.6) indicates that sedimentation was interrupted by short-lived episodes of stability during which time the surface of alluvial point bars became lightly vegetated, and so it is possible that formation of these deposits might have spanned a considerable period of time. The absence of significant deposits of floodplain alluvium, other than the thin silty clay laminae, suggests that during the early part of the Holocene, the river was well-contained within its valley in this area (Sidell et al 2000). In contrast to other sites further downstream in the Lower Thames, such as at Dartford (MOLA 2015, 2018b), the trend towards rising relative sea level (RSL) did not significantly affect sedimentation at this part of the Greenwich peninsula until much later in the Holocene, with the formation of facies 3 across the site. A sharp contact observed between the top of the facies 2 deposits and the base of facies 3 (see Photograph 4), provides further evidence for a likely hiatus in deposition between these two facies. Without direct dating of facies 2 it is impossible to determine how long this pause in sedimentation lasted for. No deposits obviously attributable to Bates and Whittaker's (2004) Stage 3 (Table 1) - equivalent to the Middle Holocene from c.6200 BC up to 2200 BC (Walker et al 2012) – have been identified at the site, and it may be that there was a considerable period of landscape stabilisation at the site during the Middle Holocene.

*Facies 3: Peats (Middle to Late Holocene / Neolithic to Bronze Age)*

The next widespread change in depositional environment at the site resulted in the formation of widespread peat deposits (facies 3). These strata range from approximately 1.2m to over 2.6m in thickness, and have an upper surface elevation of around -1m OD.

Facies 5 is the equivalent to Stage 4 of the Bates and Whittaker (2004) model (Table 1), which may be equivalent also to Devoy's (1977, 1979, 1980) Tilbury III peat, which is widespread and persistent across much of the lower Thames valley (Gibbard 1994). Devoy (1977, 1979) interpreted the Tilbury III peat as representing a major phase of marine regression (i.e. falling RSL), a view that has since been challenged (Bates and Whittaker 2004; Stafford et al 2012). Given that the peats at Greenwich Millennium Village formed directly over Early Holocene sand deposits without any preceding phase of floodplain alluviation or mudflat formation (in contrast with sites further downstream), this would seem to suggest that peat formation cannot have been caused by a fall in RSL, but must instead have been initiated in response to rising water tables (a process known as 'paludification'), almost certainly as a response to rising RSL.

Radiocarbon dating from the lower part of facies 3 in GA4 (BETA-513311, see Table 9), indicates that peat formation at the site began before 3630-3370 cal BC (95% probability), probably during the Neolithic, and this continued at least until 1740-1530 cal BC (95% probability, BETA-513312) well into the Bronze Age.

Although Ostracods and Diatoms were not generally preserved in the facies 3 strata, preservation of pollen, plant macrofossils and insect remains was generally good.

Pollen evidence suggests that facies 3 may have initially formed as a humic soil horizon during the Middle Holocene depositional hiatus at the site: the lowermost pollen-bearing sample in GA6 (P12) was interpreted as representing a palaeosol within a typical Middle Holocene lime (*Tilia*) woodland. In response to rising RSL, this on-site woodland was subsequently replaced by wet alder carr woodland. Pollen assemblages from this alder carr (l.p.a.z. GA4:1 and GA6:2) mostly reflect a highly localised pollen catchment, although the small amount of pollen derived from the surrounding dryland indicate the persistence of mixed broadleaf woodland alongside some evidence for pasture and cereal cultivation. Plant macrofossils provide further detail of the on-site alder carr environment, with an understory vegetation cover including brambles and nettles, as well as sedges, and other plants of marshy places. Insect remains likewise indicate marshy and aquatic habitats and dense woodland with the presence of dead wood, although dung beetles in one sample (I1) did indicate the presence of herbivores within the carr.

Although not distinguishable lithologically, pollen assemblages (l.p.a.z. GA6:3 and GA4:2) from the upper part of facies 3 indicate the onset of a further shift in environmental conditions towards a more open herb fen environment accompanied by a local increase in salt marsh vegetation types. This shift probably occurred as a result in an increase in the rate of RSL rise, an interpretation supported by the occurrence of marine diatoms in sample D7 (GA4 6.22-6.24m bgl). This shift, marking the first evidence for estuarine influence at the site, probably occurred during the Bronze Age, at some time after 2280-2030 cal BC (BETA-513310) but before 1740-1600 cal BC (BETA-513312).

Archaeological investigations of other broadly equivalent 'Tilbury III' peats (sensu Devoy 1980) have recovered well documented timber structures such as trackways and platforms dating to later prehistory, and the Bronze Age in particular (Meddens 1996; Carew et al 2009; Stafford et al 2012) most of which were constructed in similar landscape positions, at the margins of the floodplain and river terrace to access the river/marshland resources. Although no indications of any artefacts were noted in the boreholes at Greenwich Millennium Village, the facies 5 peats remain of high palaeoenvironmental potential.

### *Facies 4: Upper alluvium (Late Holocene / Late Bronze Age to Modern)*

Facies 4, the upper alluvium, marks a site-wide switch to the deposition of minerogenic sediments, and with that, the establishment of estuarine floodplain. Facies 6 occurs across the whole of the site, and consists in most places of greyish silt and clay dominated sediments that are up to 4m thick, although they appear to have been truncated to a varying degree by modern made ground across much, if not all of the site (see transects).

The pollen assemblage from the lower part of facies 4 in GA4 (sample P8) indicates the continuation of generally rather open conditions with the nearby presence of saltmarsh plants, although plant macrofossil evidence for scrubby vegetation and the presence of earthworm granules suggest that the site was occupied by a semi-terrestrial floodplain type environment, and that salinity is therefore likely to have been generally low.

### *Facies 5: Made ground (Late Holocene / Post-medieval to Modern)*

All of the boreholes undertaken across the site recorded modern made ground of varying composition, frequently including fragments of brick and concrete and other anthropogenic material that was deposited as a result of modern land reclamation and development. As a result, these deposits were of little palaeoenvironmental or archaeological significance.

# 6 Potential of the data

## 6.1 Realisation of the original research aims

This section examines the extent to which the original research questions listed in the WSI (MOLA 2012) have been answered by the assessment.

*Broad research questions*

- Are deposit sequences of palaeoenvironmental/geoarchaeological interest present on the site?

  *Alluvial and peat strata of palaeoenvironmental interest have been identified across the site.*

- What is the potential of these deposits to reconstruct past landscapes?

  *Useful palaeoenvironmental indicators have been identified in a number of samples from the site, especially the Middle-Late Holocene peats (facies 3). These may provide useful information about changes in RSL during this time.*

- Can the deposit sequences be assigned to a chronological framework?

  *The peat strata have been successfully radiocarbon dated, which have provided a robust chronology for their formation.*

- Is there evidence of dryland soil horizons, which may contain evidence of human occupation, present within the deposit sequence?

  *There is evidence that a soil horizon formed at the base of facies 3 during the Middle Holocene, although no direct evidence of human occupation was found from this horizon.*

- What is the level of modern truncation across the site?

  *Modern truncation varies across the site, reaching down to below 0m OD in some places (GA6).*

*Specific aims*

- Establish the date and environment represented by the basal sands and sandy silts (Facies 2), and the archaeological/palaeoenvironmental potential of these deposits;

  *This assessment has shown that the basal sands formed in a freshwater alluvial environment. Although not directly dated, this assessment has shown that the sands must pre-date the end of the Middle Holocene, and the presence of cold-climate ostracods may indicate that formation began during the Late Pleistocene.*

- Establish whether any evidence for landscape stability, a hiatus in deposition, or soil formation exists at the surface of the gravel (Facies 1) and/or the basal sands (Facies 2), and the potential for any such land surfaces for evidence of prehistoric activity;

  *Pollen evidence suggests that a hiatus accompanied by soil formation existed at the surface of the facies 2 sands, although no specific evidence for on-site human occupation or activity was found.*

- Establish the date of peat (Facies 3) development across the site and whether it was diachronous, as well as the environments represented by the peats and their archaeological/palaeoenvironmental significance;

  *Peat development at the site appears to have begun in the Neolithic and persisted until the Bronze Age. Although accumulation rates across the site appear to be consistent, the onset of peat formation may have been somewhat time-transgressive, beginning slightly (perhaps ~100-500 years) earlier in the north of the site than in the south.*

- Establish the environment of deposition of the alluvial clays (Facies 4), whether they are truncated, and whether evidence for the pre-industrial land surface survives;

  *The alluvial clays (facies 4) were deposited in a semi-terrestrial floodplain environment with some evidence for nearby estuarine influence. The surface of the upper alluvium appears to have been truncated to a varying extent across the whole of the site.*

- Investigate the date and archaeological/environmental significance of any channels crossing the site.

  *A possible channel feature has been noted in the surface of the Pleistocene gravel (facies 1), running roughly south-west to north east across the site, and infilled by Early Holocene sands (facies 2). This feature is likely therefore to be Late Pleistocene to Early Holocene in date. Few palaeoenvironmental indicators were preserved in the fills of this feature, and no indications of human activity or occupation associated with this channel were noted.*

# 7 Significance of the data

The lithological and palaeoenvironmental work carried out on the core samples from Greenwich Millennium Village fits well with the wider deposit modelling across this area of the Lower Thames.

The lithostratigraphy of the site indicates a series of discrete phases of deposition spanning much of the Late Quaternary. Of particular significance and interest to the wider Quaternary science and archaeological research community is the evidence for environmental changes in response to rising RSL during the Holocene: the onset of alder carr formation in the Middle Holocene, and the subsequent onset of more open estuarine conditions in the Late Holocene.

The data gathered and evidence preserved in the samples collected from the site should be regarded as having local significance in understanding the Lower Thames floodplain, tracking environmental change throughout the Holocene from a Mesolithic freshwater alluvial environment, to a late prehistoric wooded wetland, and finally an open estuarine floodplain. The results already obtained have provided information that has significance for reconstructing how this landscape was utilised and exploited and the response of the floodplain landscape to local and regional factors

The data from the site have significance for the wider research community in their ability to provide useful information about the influence of rising sea levels on local depositional environments in east London (Sidell and Wilkinson 2004; Carew et al 2009; Stafford et al 2012). As such, further analysis and publication of the results from Greenwich Millennium Village would be of interest to archaeologists and Quaternary Scientists working in the Lower Thames area.

# 8 Publication project: aims and objectives

## 8.1 Revised research aims

The assessment has answered the original research questions and identified a small number of revised research aims (RRA), which have been highlighted by the potential of the data and which might be addressed by limited further analysis and/or examination of the site records. These are listed below.

**RRA 1**: Can the deposits throughout the profile be more closely dated?

The dating undertaken for the assessment phase has obtained a broad chronological framework for the deposits sampled in the boreholes. As the assessment has elucidated several phases of environmental change throughout the facies 3 strata, further dating may elucidate the timing of these environmental changes (e.g. the switch to estuarine herb fen towards the top of the facies 3 strata).

**RRA 2**: Can further work on the pollen sequence refine the understanding of the prehistoric (e.g. Neolithic and Bronze Age) vegetation and landscape development?

The assessment indicated reasonable preservational conditions for pollen throughout the facies 3 peats. Although useful information has been gained from this preliminary study, interpretation is based on a limited number of samples spanning a substantial thickness of sediment. Additional analysis of a small number of samples would provide better stratigraphic resolution that would add local detail to the general vegetation succession and patterns of human activity.

**RRA3:** Can further analysis of key transitions in the sedimentary sequence be developed to provide information on the rate of RSL rise during the Middle and Late Holocene?

The assessment has demonstrated that key transitions such as the establishment of alder carr wetland and the later switch to estuarine herb fen may have the potential to provide useful data on the rate of RSL rise in the Middle and Late Holocene, and the resulting expansion of wetland environments in the vicinity of the site. Although ostracods and diatoms have been shown to be poorly preserved, the organic nature of the facies 3 strata are likely to be conducive to the preservation of testate amoebae, which can provide useful information on water table/tidal levels (Charman et al 1998; Mitchell et al 2007; Amesbury et al 2016; Barnett et al 2017).

## 8.2 Preliminary publication synopsis

The results obtained within this report, in conjunction with the results of targeted further analysis should be published as a short report in an appropriate local archaeological journal. It is envisaged that the publication will comprise an article, which incorporates the lithological evidence with the palaeoenvironmental specialist work to reconstruct the depositional history of the site, with particular emphasis on reconstructing the prehistoric landscape in relation to Middle and Late Holocene sea level rise.

## 8.3 Publication project: task sequence

The various tasks to complete the publication are outlined below.

Geoarchaeological method statement

Task 1 Integrate specialist analysis with lithology to revise the understanding of the deposit sequence.

Task 2 Correlation of deposit sequence with the present models of Thames floodplain evolution (i.e. Bates and Whittaker and Devoy's Thames\Tilbury sequence) and other local sequences.

Task 3 Figure preparation, producing topographic plots and transects illustrating site stratigraphy.

Pollen method statement

Task 4 Preparation of pollen samples for submission to specialist.

Task 5 Additional analysis on 6 pollen samples from GA6 to refine pollen assemblage and refine pollen zones. Includes report text.

Radiocarbon dating method statement

Task 6 Submission of additonal sample of alder catkins from GA6 (4.65-5.00m bgl).

Task 7 AMS dating of sample.

Testate amoebae method statement

Task 8 Preparation of 8 testate amoebae samples for assessment.

Task 9 Assessment of 8 testate amoebae samples from GA6 facies 3 strata.

Task 10 Data entry, analysis of results and production of report text.

Graphics method statement

Task 11 Drawing office input to production of site location plans, topographic plots, transects, sections and sample location data, with corrections.

Publication text method statement

Task 12 Prepare draft publication text

Task 13 Edit specialist contributions and integrate into publication text

Task 14 Technical edit

Task 15 Corrections to text

Archive method statement

Task 16 Preparation and deposition of archive

Publication

Task 17 Costs associated with publication

Project management method statement

Task 18 Project management, quality control, submission of article

# 9 Publication project: resources and programme

Financial resources sufficient to cover the work proposed in this document will be sought via a separate document if necessary.

| Task No. | Task Description | Time required (person days) |
|---|---|---|
| Task 1 | Integrate specialist analysis (pollen, radiocarbon dating, ostracod/ diatoms, plant macro fossils) with lithology to revise the understanding of the deposit sequence. | 1 |
| Task 2 | Correlation of deposit sequence with the present models of Thames floodplain evolution (i.e. Bates and Whittaker and Devoy's Thames\Tilbury sequence) and other local sequences. | 1 |
| Task 3 | Figure preparation, producing topographic plots and transects illustrating site stratigraphy. | 1 |
| Task 4 | Preparation of pollen samples for submission to specialist. | 0.5 |
| Task 5 | Additional analysis on 6 pollen samples from GA6 to refine pollen assemblage and redefine pollen zones. Includes report text. | external specialist |
| Task 6 | Preparation of a further radiocarbon samples from LBK17 BH2 and LBK17 BH6. Submit samples. | 0.25 |
| Task 7 | AMS dating | external lab |
| Task 8 | Preparation of testate amoebae samples | 2 |
| Task 9 | Assessment of 8 testate amoebae samples from GA6 facies 3 strata. | 2 |
| Task 10 | Data entry, analysis of results and production of report text. | 1 |
| Task 11 | Drawing office input to production of site location plans, topographic plots, transects, sections and sample location data, with corrections | 1.5 |
| Task 12 | Prepare draft publication text | 5 |
| Task 13 | Edit specialist contributions and integrate into publication text | 1 |
| Task 14 | Technical edit | 1 |
| Task 15 | Corrections to text | 1 |
| Task 16 | Preparation and deposition of archive | 1 |
| Task 17 | Costs associated with publication | - |
| Task 18 | Project management, quality control, submission of article | 2 |

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# 11 Appendix 1: management, delivery and quality control

MOLA (Museum of London Archaeology) is a company limited by guarantee registered in England and Wales with company registration number 07751831 and charity registration number 1143574. The Registered Office is Mortimer Wheeler House, 46 Eagle Wharf Road, London N1 7ED). It has its own independent Board of Trustees but works in partnership with the Museum of London via a Memorandum of Understanding.

MOLA is a 'Registered Organisation' with the archaeological professional body, the Chartered Institute for Archaeologists (CIfA). The C*IfA Register* is a rigorous Quality Assurance scheme for archaeologists. In order to be accepted, MOLA has passed a Board resolution to comply with the CIfA Code of Conduct and Standards, to demonstrate that compliance through bi-annual re-registration, to submit to regular CIfA inspections, and to ensure that all MOLA activities are under the overall direction of a Member grade (MifA) 'responsible post-holder'. The Registered Organisation scheme also provides procedures for investigating and handling of external complaints.

MOLA subscribes to and abides by the general principles and specific terms of the *Code of Good Practice On Archaeological Heritage in Urban Development Policies* established by the Cultural Heritage Committee of the Council of Europe, and adopted at the 15th plenary session in Strasbourg on 8-10 March 2000 (CC-PAT [99] 18 rev 3). In particular to the following points: ….a*rchaeologists shall be aware of development costs and adhere to agreed timetables* (Para 3 'The Role of the Archaeologist'), with all work *'carried out to written statements setting out standards timetables and costs'* (para 4 ibid).

MOLA further subscribes to and ensures that its activities comply with and/or are guided by the following policies, procedures and guidance:

- Appropriate local and regional planning authority archaeology guidance – e.g. for London: English Heritage, Standards for *archaeological work* (2014)
- Appropriate Archaeological Research Framework for the region – e.g. for London: English Heritage Archaeology Division, *Research Agenda* (1997); Museum of London, *A research framework for London archaeology (*2002); and *Historic Environment Research Strategy for Greater London* (in prep. CBA/MoL/Rowsome).
- English Heritage, Management of Archaeological Projects (MAP2), (1991)
- English Heritage Centre for Archaeology, *Guidelines* (various)
- Museum of London Archaeological Service*, Archaeological Site Manual (1994)*
- Museum of London Archaeological Service, *Archaeological Finds Procedure Manual* (2006)
- National archive disposition standards including Museum and Galleries Commission, *Standards in the Museum Care of Archaeological Collections* (1992) and Society of Museum Archaeologists, *Towards an Accessible Archaeological Archive: the Transfer of Archaeological Archives to Museums: Guidelines for Use in England, Northern Ireland, Scotland and Wales* (1995)
- Relevant local archive deposition standards, e.g. for London, Museum of London, General Standards for the preparation of archaeological archives deposited with the Museum of London, (2009).

MOLA governance and organisational strategy are determined by the Senior Management Group (SMG), led by the Chief Executive Officer and comprising the Finance Director, the Head of Operations, and four Directors heading the Planning, Development Services Research & Education and Northampton divisions. The SMG reports regularly to an independent Board of Trustees, who oversee

MOLA's performance and strategic direction. As a charitable company MOLA is monitored and regulated by the Charities Commission.

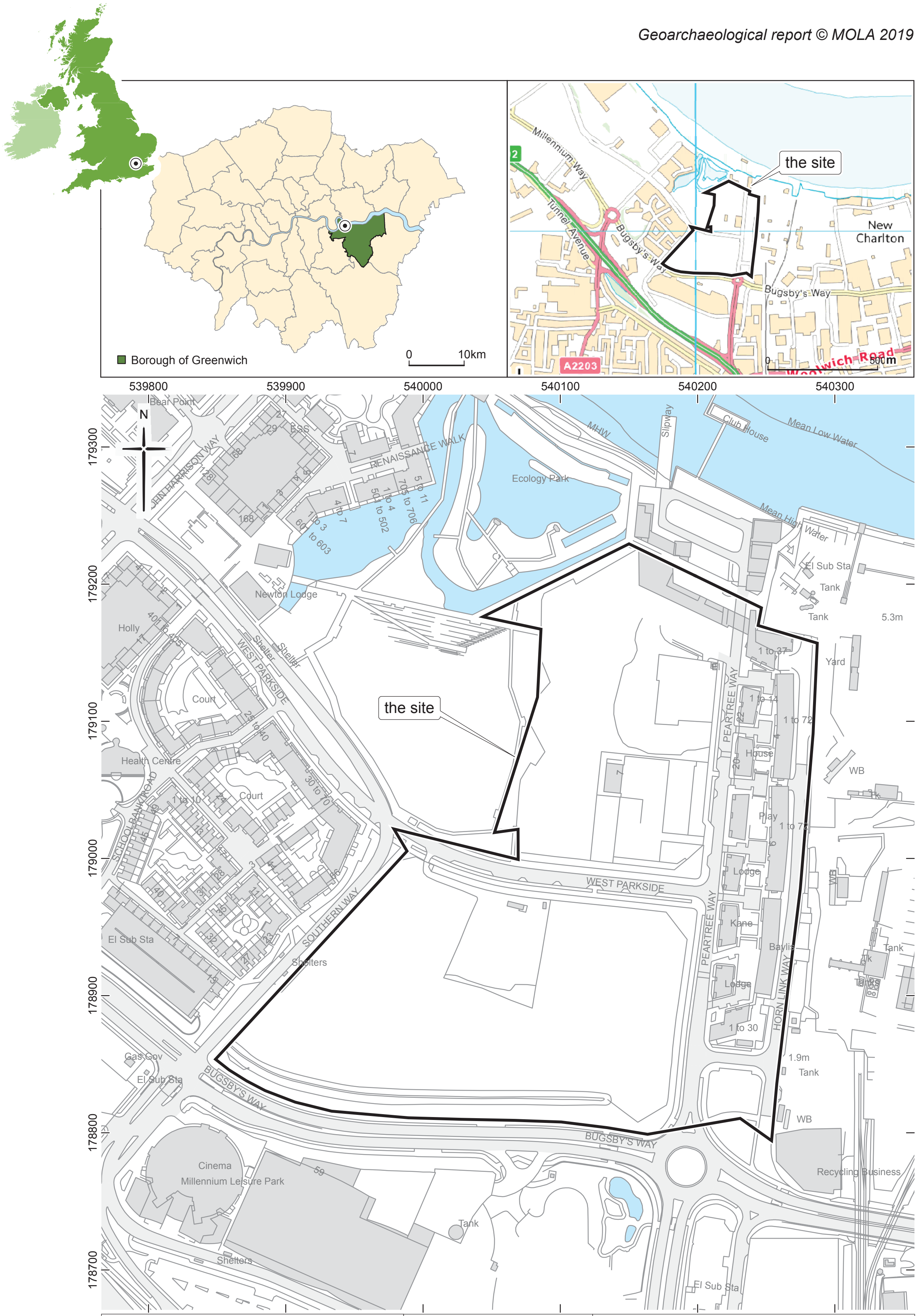
MOLA is structured to reflect its project orientation. Within Development Services the Director manages the Client Team of c 10 Project Managers (PMs). Individual PMs are responsible for developing new work for MOLA, and thereafter for designing, budgeting and delivering projects for clients. They remain the principal point of contact for the client for the duration of each project.

PMs drive projects through successive stages in accordance with client needs, forming project teams by drawing upon the skills available within MOLA Operations teams. PMs ensure that projects are completed to the highest standards within time and budget. Financial monitoring of projects against budget is undertaken by the Finance Director and PMs at monthly review meetings. Project management software is employed by MOLA Operations to plan resourcing and track and adhere to programme and budget. Project team meetings are held throughout the programme, allowing refinement of research strategies in the light of on- or off-site findings or analysis. Recording, excavation, and sampling strategies may be modified to provide optimum information retrieval in support of the research objectives. At post-excavation phase internal project management is normally devolved to a designated Post-Excavation Project Manager.

All archaeological field work is controlled and monitored on a day to day basis by the on-site Site Supervisor (SS), who reports to the designated Project Manager. Together with PMs and the Field Manager (responsible for H&S) they also liaise as necessary with the client's agents and principal contractors regarding all enabling works and H&S..

All written documentation, e.g. initial '*written scheme of investigations' ('wsis')*, evaluation reports, post-excavation *Assessment Report*s and final publications undergo stages of internal review and sign-off prior to final issue to clients. For both field and reporting work PMs and SSs meet and liaise with the client and the Local Authority's archaeological advisor or officer to ensure delivery according to wsis and to review progress, research aims, archaeological procedures, and site strategies as appropriate.

At all stages, what constitutes an appropriate archaeological response will be assessed against criteria of local, regional and national significance and within frameworks of valuable archaeological research topics identified in local or regional Archaeological Research Frameworks (where these exist).






scale 1:4,000 @ A4

0 100m

Fig 1 Site location

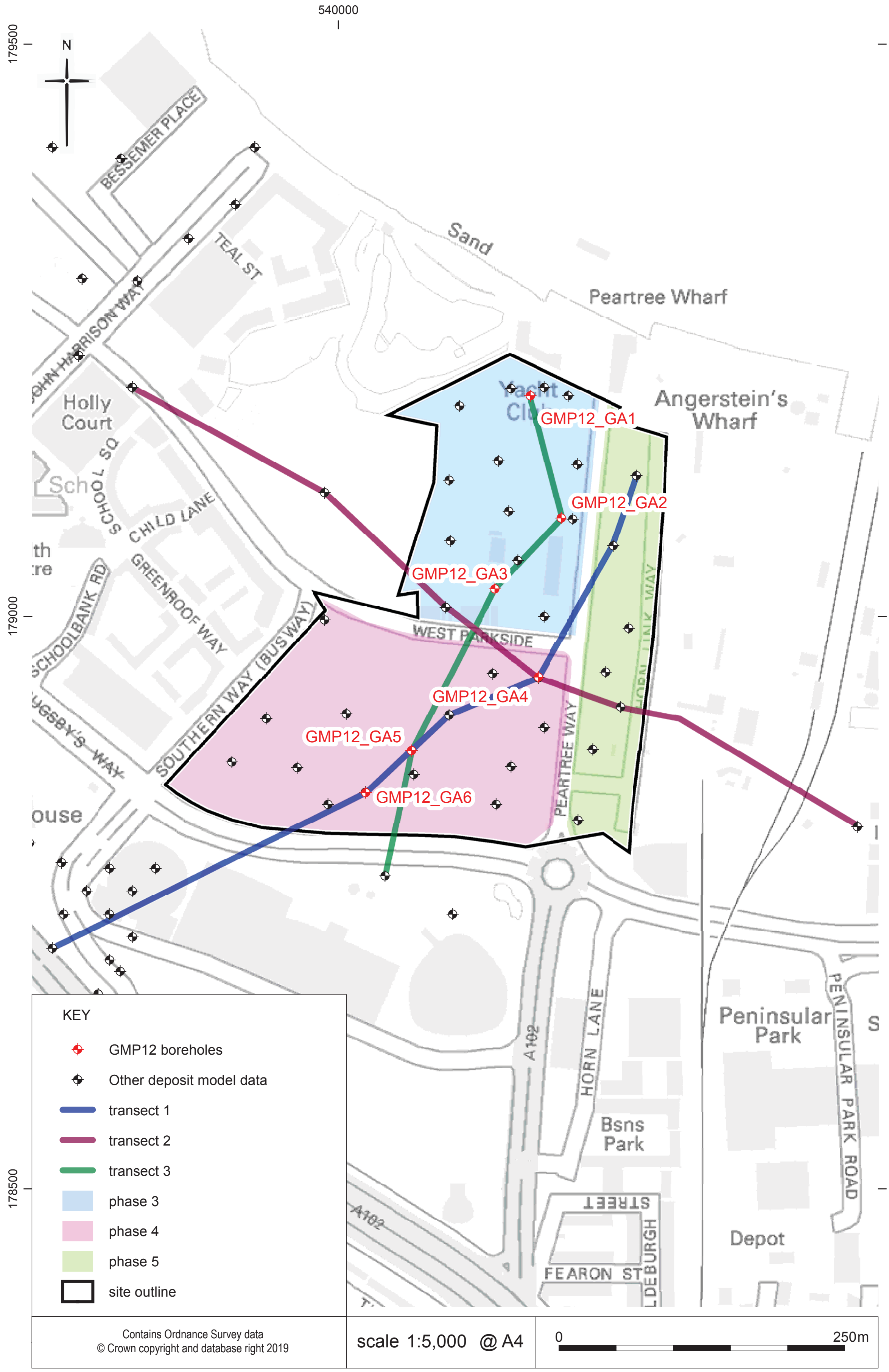



Fig 2 Location of geoarchaeological boreholes

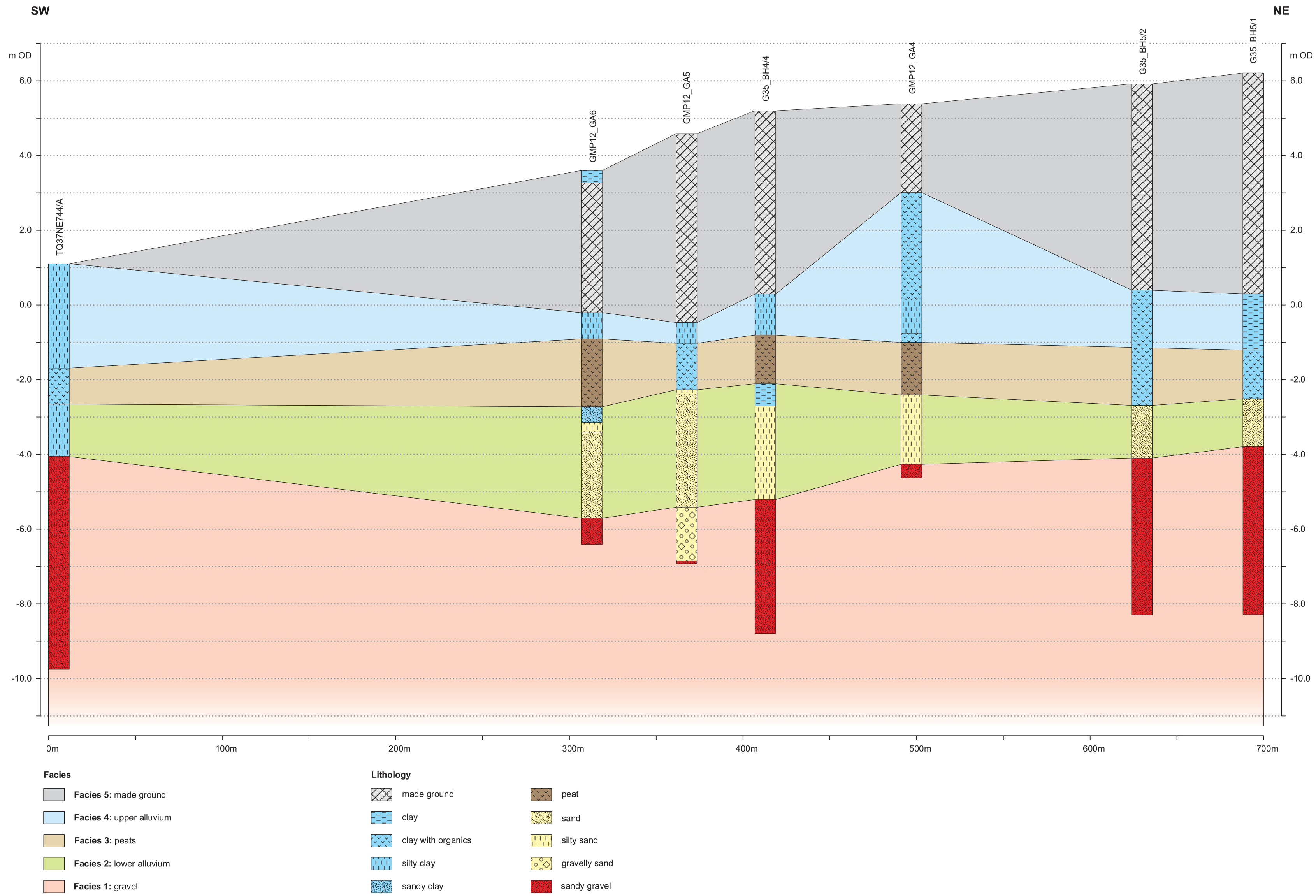



Fig 3 Borehole transect 1 from south-west to north-east across the site

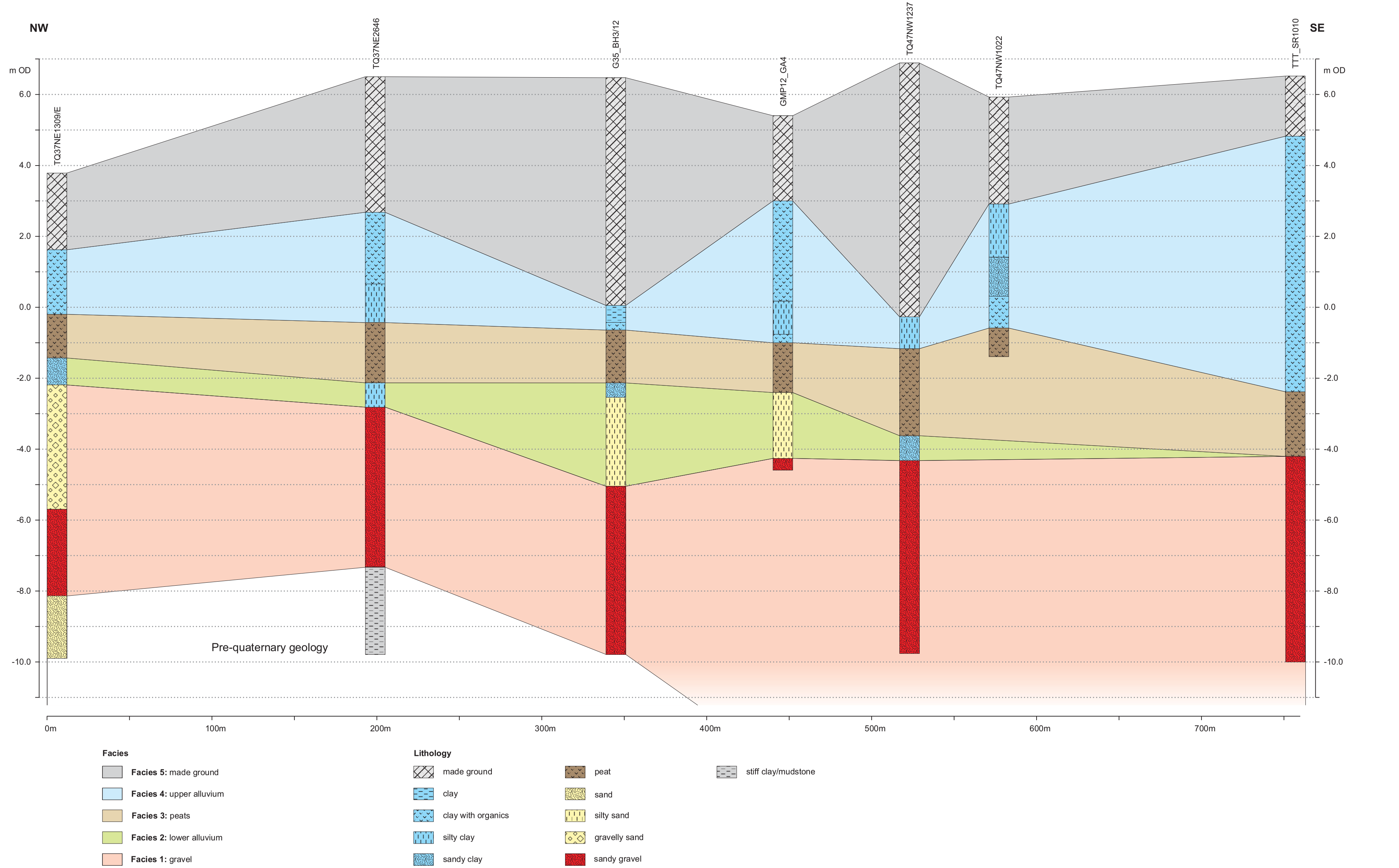



Fig 4 Borehole transect 2 from north-west to south-east across the site

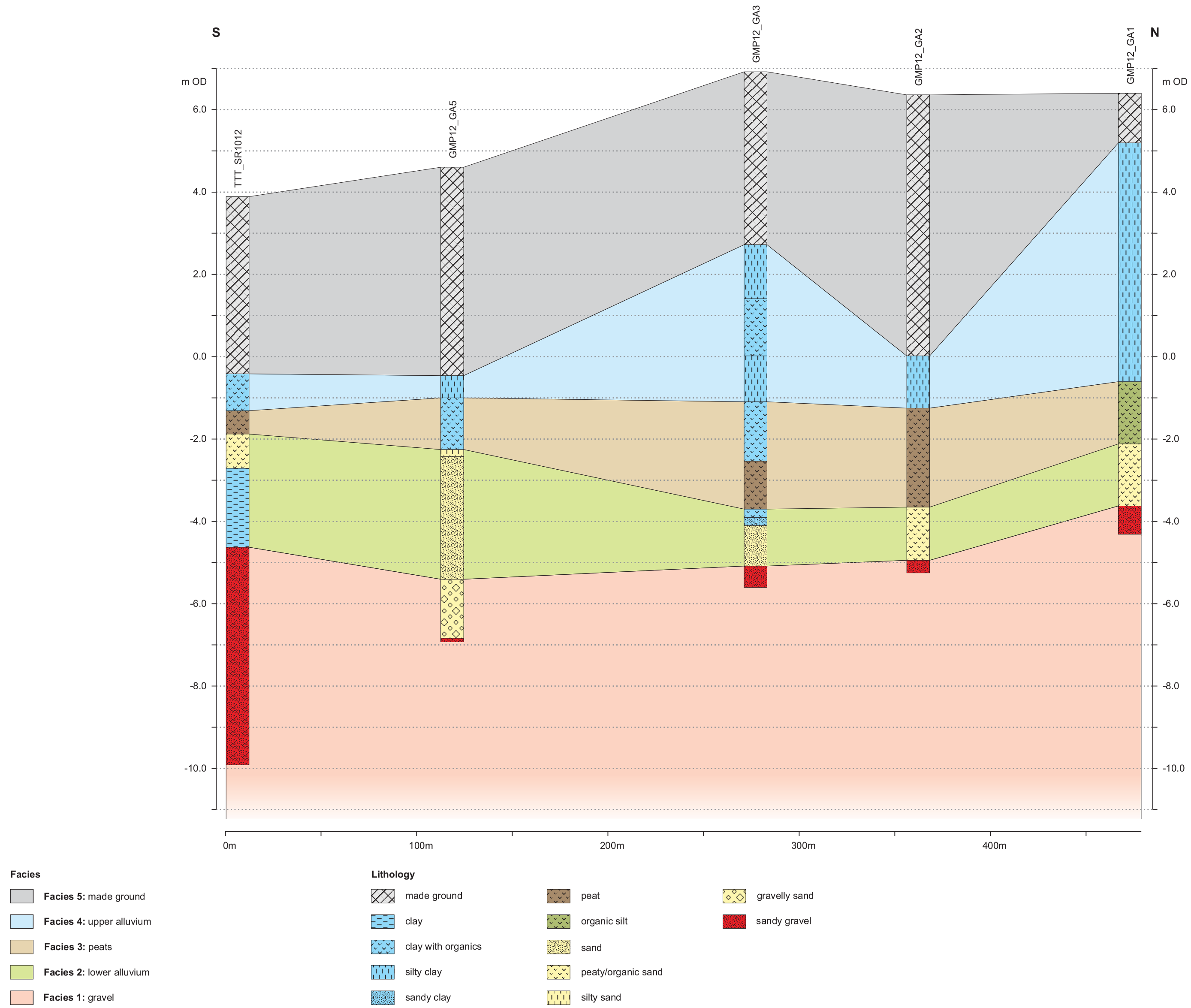
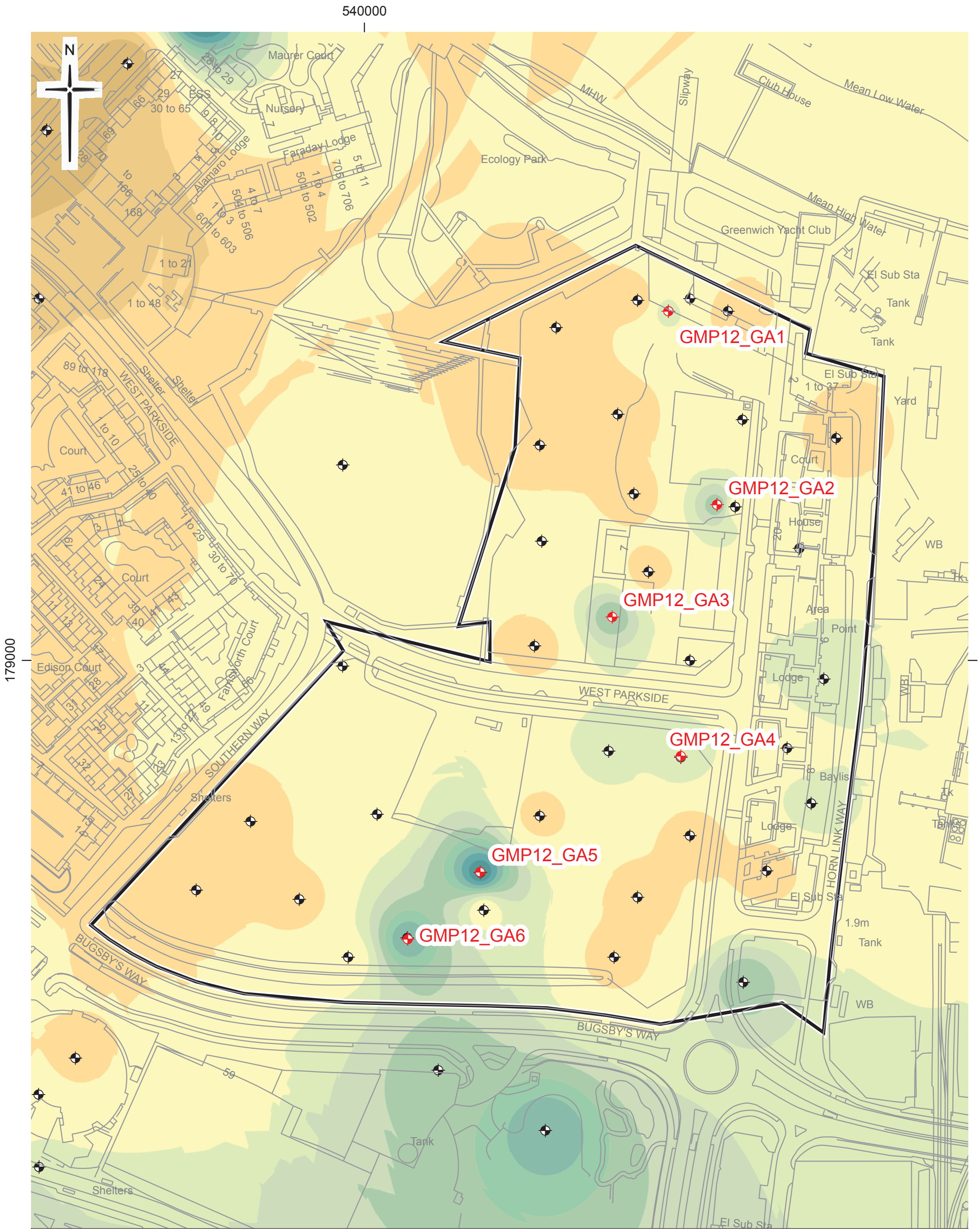



Fig 5 Borehole transect 3 from south to north across the site




KEY

- GMP12 boreholes
- Other deposit model data
- site outline

**Early Holoce surface**

| | |
|---|---|
| -7 to -6.5m OD | -3 to -2.5m OD |
| -6.5 to -6m OD | -2.5 to -2m OD |
| -6 to -5.5m OD | -2 to -1.5m OD |
| -5.5 to -5m OD | -1.5 to -1m OD |
| -5 to -4.5m OD | |
| -4.5 to -4m OD | |
| -4 to -3.5m OD | |
| -3.5 to -3m OD | |



scale 1:3,500 @ A4

0 100m

Fig 6 Modelled elevation of the Early Holocene surface

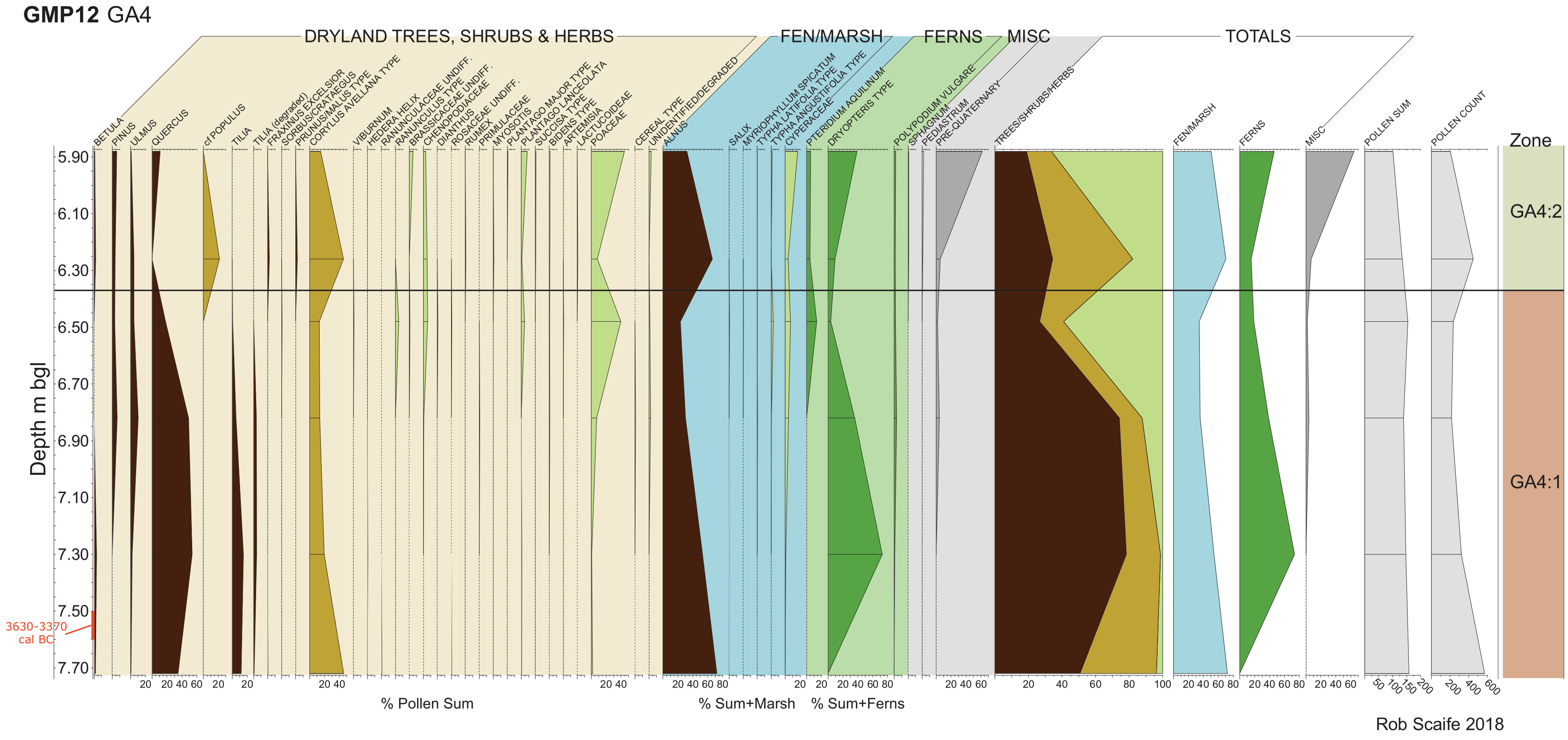



Fig 7  GA4 pollen diagram

GREE1053GEO19#07

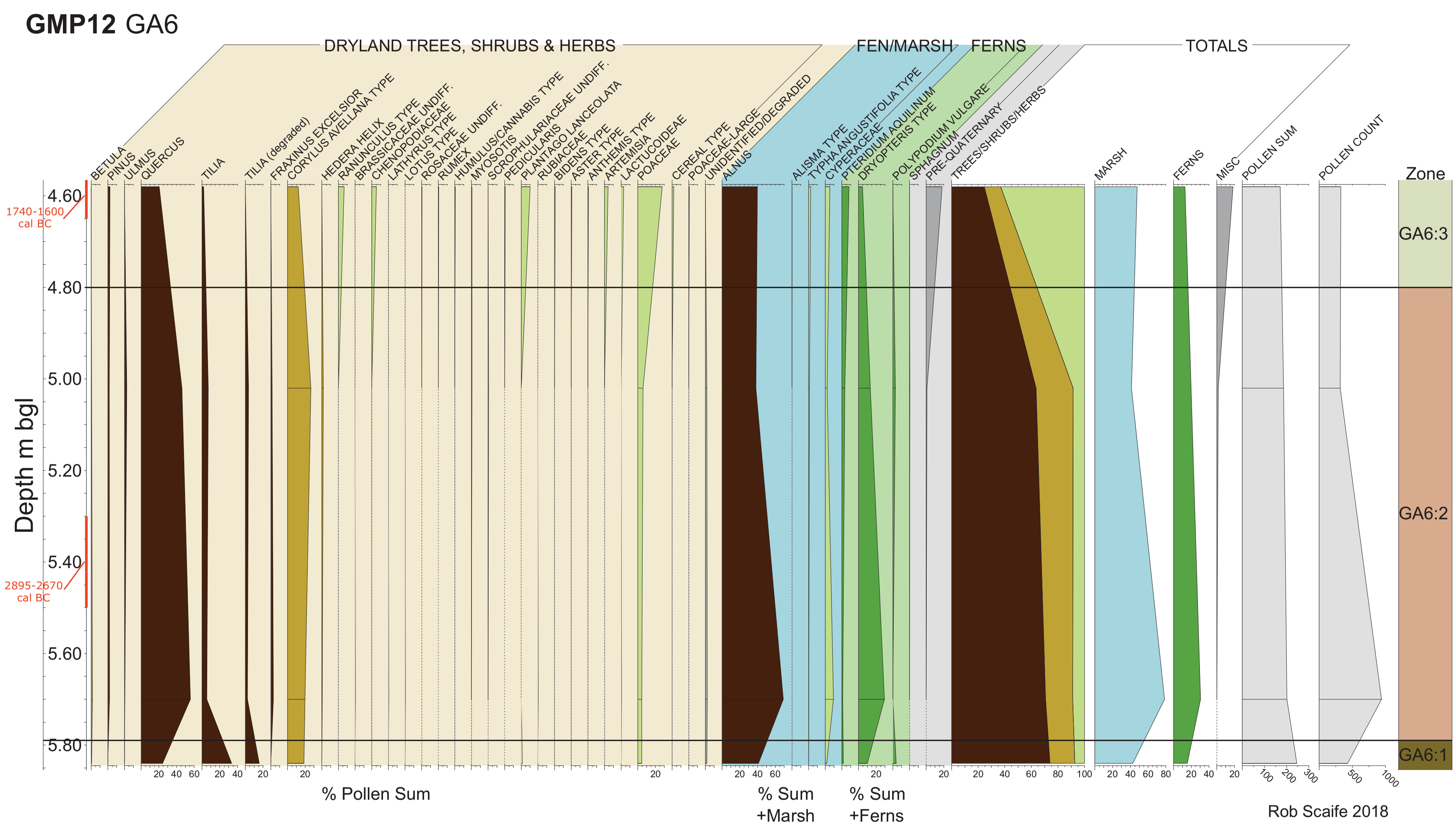



Fig 8 GA6 pollen diagram

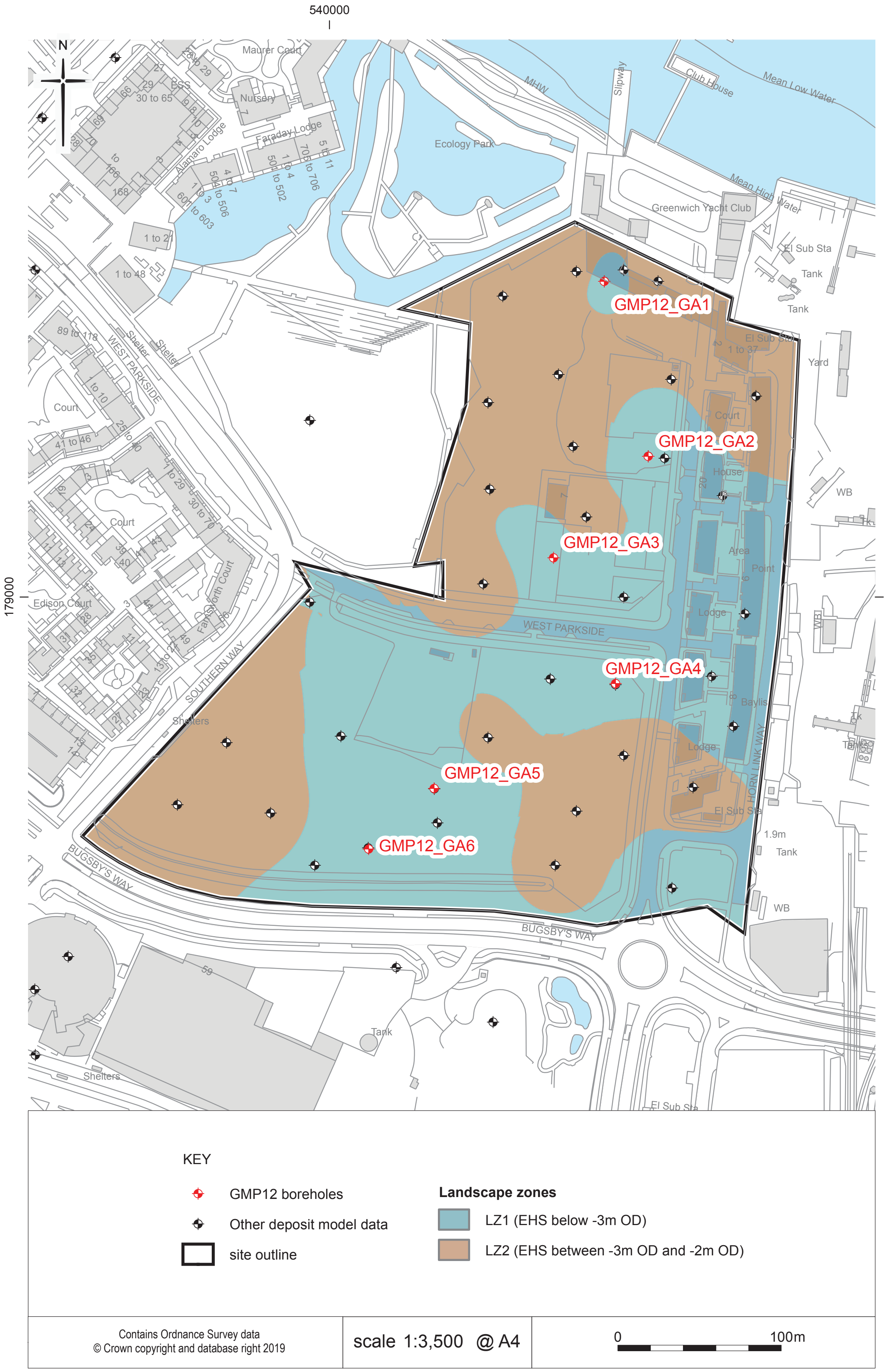



Fig 9 Landscape zones

# 12 OASIS archaeological report form

## OASIS ID: molas1-340220

### Project details

| | |
|---|---|
| Project name | Greenwich Millennium Village Geoarchaeological Post Excavation Assessment |
| Short description of the project | This document reports on the results of a geoarchaeological investigation undertaken by Museum of London Archaeology (MOLA) on the site of Greenwich Millennium Village, London SE10. This report has been commissioned from MOLA by Environ on behalf of Taylor Wimpey plc. The centre of the site lies at National Grid reference 540150 179000. The site code is GMP12. Six purposive geoarchaeological boreholes were sunk across the site, revealing a Quaternary sedimentary sequence comprising Pleistocene floodplain gravels overlain by Late Pleistocene to Holocene sediments comprising (Late Pleistocene to Early Holocene bedded alluvial sands, Middle to Late Holocene organic muds and peats and Late Holocene mineral floodplain alluvium capped by modern made ground. In order to explore the palaeoenvironmental potential of the site, subsamples were taken from two boreholes, GA4 and GA6, for radiocarbon dating and pollen, plant macrofossil, ostracod, diatom and insect assessments. These assessments have revealed a series of environmental changes spanning the late Quaternary with particular focus on the palaeoenvironment of the vegetated wetland environments that formed on the site during the Middle and Late Holocene. This assessment has provided an outline of the changing palaeoenvironment throughout much of the Late Quaternary in this part of the Lower Thames valley. Some samples from the site have been shown to have high potential to provide a more detailed picture of these changes. |
| Project dates | Start: 06-06-2018 End: 18-01-2019 |
| Previous/future work | Yes / Not known |
| Any associated project reference codes | GMP12 - Sitecode |
| Any associated project reference codes | molas1-144763 - OASIS form ID |
| Any associated project reference codes | molas1-164043 - OASIS form ID |
| Type of project | Environmental assessment |
| Monument type | NONE None |
| Significant Finds | PEAT Neolithic |
| Significant Finds | PEAT Bronze Age |
| Survey techniques | Archaeology |
| Survey techniques | Ecology |

| | |
|---|---|
| Survey techniques | Landscape |
| Survey techniques | Soils |

## Project location

| | |
|---|---|
| Country | England |
| Site location | GREATER LONDON GREENWICH GREENWICH Greenwich Millennium Village |
| Postcode | SE10 |
| Study area | 11 Hectares |
| Site coordinates | TQ 40150 79000 51.492047154762 0.019019334778 51 29 31 N 000 01 08 E Point |

## Project creators

| | |
|---|---|
| Name of Organisation | MOLA |
| Project brief originator | ENVIRON UK LTD |
| Project design originator | MOLA |
| Project director/manager | Craig Halsey |
| Project supervisor | Phil Stastney |

## Project archives

| | |
|---|---|
| Physical Archive Exists? | No |
| Digital Archive recipient | London Archaeological Archive |
| Paper Archive recipient | London Archaeological Archive |

## Project bibliography 1

| | |
|---|---|
| Publication type | Grey literature (unpublished document/manuscript) |
| Title | GREENWICH MILLENNIUM VILLAGE Greenwich London SE10. Geoarchaeological post-excavation assessment and updated project design |
| Author(s)/Editor(s) | Stastney, P. |
| Date | 2019 |
| Issuer or publisher | MOLA |

| | |
|---|---|
| Place of issue or publication | London |
| Entered by | Phil Stastney (pstastney@mola.org.uk) |
| Entered on | 21 January 2019 |