A REPORT ON THE GEOARCHAEOLOGICAL BOREHOLE INVESTIGATIONS AND DEPOSIT MODELLING ON THE LONDON CABLE CAR ROUTE, LONDON BOROUGHS OF NEWHAM AND GREENWICH (site code: CAB11)

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INTRODUCTION

This report summarises the findings arising out of the geoarchaeological borehole investigations and deposit modelling undertaken by Quaternary Scientific (University of Reading) in connection with the proposed Cable Car development in the London Boroughs of Newham and Greenwich (National Grid Reference: spanning TQ 40111 80696 (north) to 39478 79745 (south); site code: CAB11). The site spans Bugsby's Reach of the tidal River Thames between the North Greenwich 'peninsula' (meander core) on the right (south) bank and the Royal Victoria Dock on the left (north) bank. The site itself was divided into five main areas in which new geotechnical investigations (test pits, window samples, cable percussion boreholes and rotary boreholes) were being carried out by Soil Mechanics on behalf of Mott MacDonald, as follows: (1) the North Station (NS); (2) the North Intermediate Tower (NIT); (3) the North Tower (NT); (4) the South Tower (ST), and (5) the South Station (SS) (Figure 2). In addition two overwater boreholes were put down as part of a future potential tunnel project within the course of the River Thames (TU). The ground within the site on both the north and south bank originally formed part of the natural floodplain of the Thames and is underlain by river alluvium (British Geological Survey 1:50,000 sheets 256 North London 1993, 257 Romford 1996, 270 South London 1998, 271 Dartford 1998). Beneath the alluvium, sand and gravel is present and is assigned by Gibbard (1994) to the Late Devensian Shepperton Gravel. In the Canning Town/ Woolwich area, Gibbard (1984, Fig.48) shows a thickness of 5.0m to 8.0m of Shepperton Gravel with a surface at *ca*. -2.0m to -3.0m OD. In the same transect, he shows *ca*. 2-3m of alluvium (Tilbury Deposits) overlying the Shepperton Gravel with the surface of the alluvium between 0.0m and 1.0m OD. The bedrock beneath the site is the Paleocene London Clay.

The natural floodplain topography both to north and south of the river has been extensively transformed by industrial land-use in the 19th and 20th centuries, particularly in the vicinity of the Royal Victoria Dock which was opened in 1855. Excavations to form the dock must have extended below the level at which the dock sill was formed at 28' below OD (8.53m). Elsewhere, almost everywhere within the site, Made Ground has raised the ground surface level, often by as much as 4-5m.

Investigations of the Holocene alluvial deposits at localities close to the present site have revealed a rather consistent stratigraphic scheme on the north side of the river. In a series of boreholes put down immediately to the south of the Royal Victoria Dock, Wilkinson *et al* (2000) recorded the surface of the Shepperton Gravel between -3.3m and -1.6m OD, overlain by a sequence of organic clays and silts in which a peat horizon was present either resting directly on the underlying gravel or separated from it by organic silts and clays. The onset of peat accumulation was radiocarbon dated to 6670-6280 cal yr BP with peat formation continuing for 2500-3000 years and dates for the apparent cessation of peat formation ranging from 4240-3850 cal yr BP to 2690-2160 cal yr BP. The peat was overlain by silt-rich estuarine muds at levels mainly between -0.5m and -1.2m OD, but rising in one borehole to +1.2m OD.

Also on the north side of the river, Batchelor (2010) recorded similar conditions in boreholes immediately to the north of the Royal Albert Dock with the surface of the Shepperton Gravel at -1.63m OD, peat and organic clay between -1.63m OD and -1.0m OD and mineral sediments above this level. A radiocarbon date of 4410-4080 cal yrs BP was obtained near the bottom of the peat and a date of 3630-3360 cal yrs BP near the top.

On the south side of the river, Gibbard (1994) illustrates a transect in the North Greenwich area (Figs 42), based on some 35 boreholes along the A102 (M) Blackwall Tunnel south approach road. This shows the uneven surface of the bedrock Paleocene sediments at levels from *ca*. -7.0m OD down to below -12.0m OD. The surface of the Shepperton Gravel is also uneven, between c.-5.0m OD and c.-2.0m OD, and the gravel is overlain by alluvial deposits between 2m and 5m thick. The alluvial deposits are truncated in many places and extensively overlain by Made Ground but the original floodplain surface appears to have been close to 1.0m OD. Within the alluvial sequence, a peaty horizon is recorded in 30 of the boreholes and varies in thickness from less than a metre up to *ca*. 4m. In 12 of the boreholes the peaty horizon rests directly on the surface of the Shepperton Gravel. In the remaining boreholes a unit of sand or sandy clay, or less commonly silt and clay, separates the peaty horizon from the Shepperton Gravel. The surface of the peaty horizon is rather uniformly between -1.0m OD and -2.0m OD, rising at the northern end of the transect closer to 0.0m OD. Towards the southern end of the North Greenwich peninsula at Bellot Street (NGR: TQ 3935 7849), close to the margin of the alluvial floodplain, peat was recorded by Branch et al (2005) at levels between -0.12m OD and -1.16m OD. A wooden trackway within the peat unit was radiocarbon dated to between 3890-3680 cal yrs BP and 3720-3570 cal yrs BP.

The main aims of the new geoarchaeological investigations along the Cable Car route were to produce a basic model of the sub-surface stratigraphy across the site and to collect samples of potential geoarchaeological significance. In order to accomplish these aims, the following objectives were formulated:

(1) To monitor and record selected geotechnical boreholes being put down in each of the five areas of the Cable Car route
(2) To select a minimum of two geoarchaeological borehole sequences from each side of the River Thames for assessment and analysis (if necessary), based upon the results of the geotechnical borehole monitoring
(3) To carry out a detailed laboratory-based description of the newly collected geoarchaeological borehole core samples
(4) To carry out a systematic and detailed review of existing data from previous geotechnical records collected in the area
(5) To produce 2-Dimensional models of the surfaces and thicknesses of the main stratigraphic units across the site


TOWER HAMLETS
Bromley
Mile End
Bow Common
Limehouse
POPLAR
South Bromley
Blackwall
Canning Town
Plaistow
Beckton
Custom House
Exhibition Centre
Royal Victoria Dock
Albert Dock
London City Airport
King George V Dock
Silvertown
North Woolwich
ISLE OF DOGS
Millwall
Cubitt Town
GREENWICH
New Charlton
Charlton
River Thames
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Figure 1: Location of (1) the Cable Car route ((A) North Station; (B) North Intermediate Tower; (C) North Tower; (D) South Tower; (E) South Station), London Boroughs of Newham and Greenwich and other nearby locations: (2) Bryan Road (Tucker, 1993); (3) Atlas Wharf (Lakin, 1998); (4) Preston Road (Branch et al., 2007); (5) East India Docks (Pepys, 1665); (6) Bellot Street (Branch et al., 2005); (7) 72-88 Bellot Street (McLean, 1993; Philp, 1993); (8) Silvertown (Wilkinson et al., 2000); (9) Fort Street (Wessex Archaeology, 2000); (10) Greenwich Industrial Estate (Morley, 2003); (11) Royal Docks Community School (Holder, 1998); (12) Beckton Nursery (Divers, 1995); (13) Beckton 3D (Meddens, 1996; Truckle, 1996); (14) A13 Woolwich Manor Way (Gifford and Partners, 2001); (15) Beckton Alp (Truckle and Sabel, 1994); (16) Golfers' Driving Range (Batchelor, 2009; Carew et al., 2009); (17) Beckton Tollgate (Tamblyn, 1994); (18) East Beckton District Centre (Jarrett, 1996); (19) East Ham FC (Scaife, 2001); (20) Albert Dock (Spurrell, 1889); (21) Royal Albert Dock (Batchelor, 2009); (22) Albert Road (Spurr et al., 2001); (23) North Woolwich Pumping Station (Sidell, 2003)

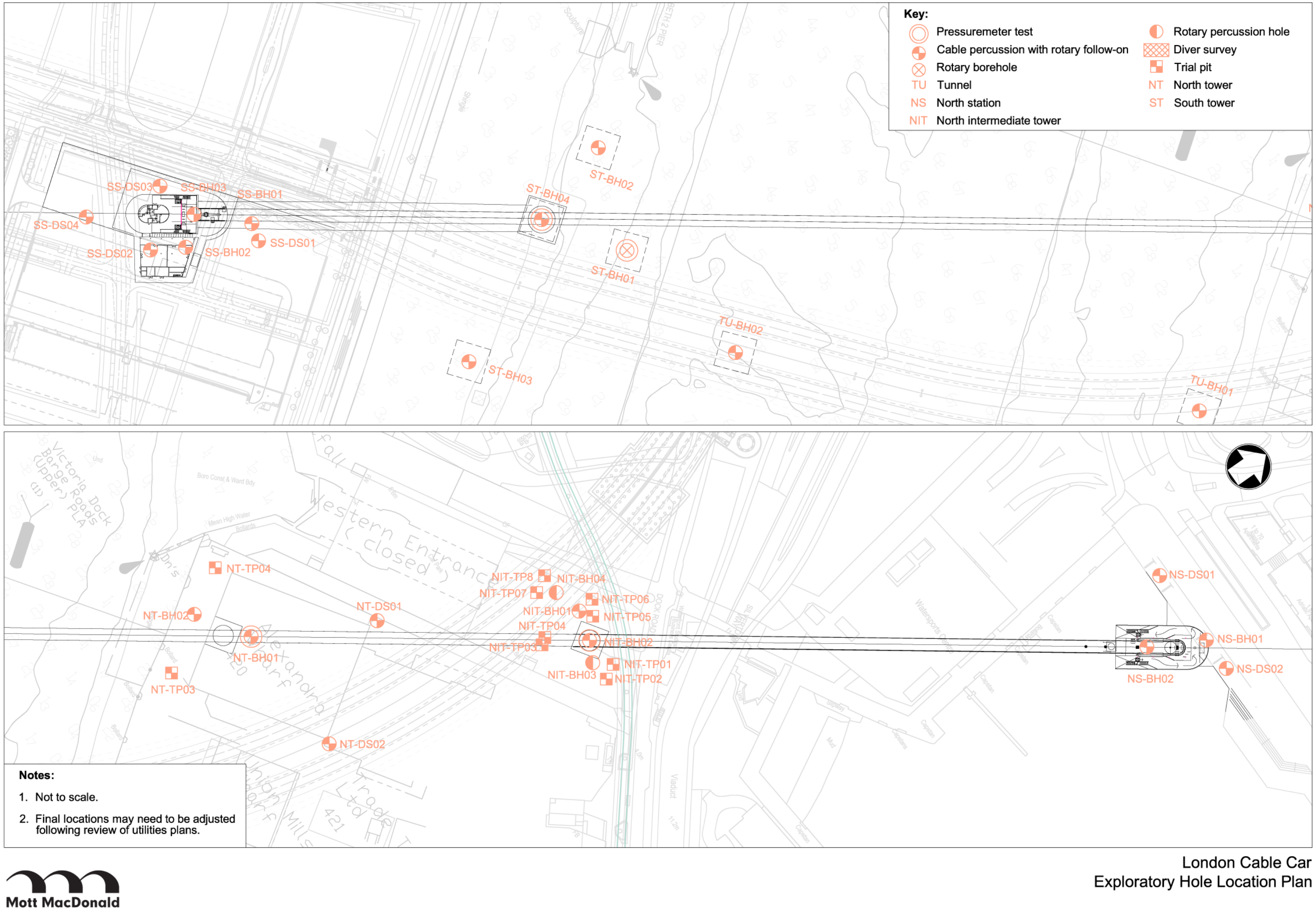

Figure 2: Detailed plan of the Cable Car route, London Boroughs of Newham and Greenwich (site code: CAB11).

METHODS

Field investigations

Geotechnical borehole monitoring

Sub-surface investigations of the North Station (NS), North Intermediate Tower (NIT), North Tower, South Tower (ST), and South Station (SS) areas of the site by Soil Mechanics between February and April 2011 provided the opportunity to monitor and record the sediments from fifty-six geotechnical boreholes and test-pits (Figure 2, Table 1) which were obtained to various specified depths below surface. Quaternary Scientific visited the site to monitor and record the Holocene deposits from select geotechnical boreholes only (NSBH01, NITBH02, NTBH01, SSBH03). The remaining boreholes/test-pits were not recorded as they were either too closely located to other monitored geotechnical boreholes or were unlikely to penetrate deep enough to reach the Holocene alluvium. However, the geotechnical logs were retrieved for subsequent use in the deposit modelling process.

Each of the selected boreholes was recorded in the field using standard procedures for recording unconsolidated sediment and peat, noting the physical properties (colour), composition (gravel, sand, clay, silt and organic matter), peat humification and inclusions (e.g. artefacts) (Troels-Smith, 1955). The procedure involved: (1) recording the physical properties, most notably colour using a Munsell Soil Colour Chart, but occasionally dryness; (2) recording the composition, including moss peat (Turfa bryophytica; Tb), wood peat (Turfa lignosa; Tl), herbaceous peat (Turfa herbacea; Th), completely disintegrated organic matter (Substantia humosa; Sh), gravel (Grana glareosa; Gg), fine sand (Grana arenosa; Ga), silt (Argilla granosa; Ag) and clay (Argilla steatoides); (3) recording the degree of peat humification, and (4) recording the boundary changes e.g. sharp or diffuse. The results of the field based descriptions are provided in Tables 2 to 6.

Table 1: Details of the geotechnical boreholes from the North Station (NS), North Intermediate Tower (NIT), North Tower, South Tower (ST), and South Station (SS) areas of the Cable Car, London Boroughs of Newham and Greenwich (site code: CAB11)

Borehole number	Easting	Northing	Depth at surface (m OD)
NS			
NSDS01	540111.26	180696.07	5.32
NSBH01A	540152.83	180702.12	4.87
NSBH01*	540152.91	180700.09	4.85
NSDS02	540167.03	180696.54	4.54
NSBH02	540135.76	180672.33	-5.52
NIT			
NITBH06	539951.44	180418.42	5.43
NITTP04	539948.69	180419.02	5.38
NITTP04A	539946.91	180419.66	5.34
NITTPH03	539969.51	180429.48	5.39
NITBH05	539980.00	180428.72	5.46
NITTP01	539973.66	180435.92	5.33
NITBH02*	539972.81	180437.25	5.28
NITBH09	539961.27	180443.27	5.18
NITBH09A	539960.26	180442.76	5.21
NITBH09B	539957.29	180440.72	5.18
NITB09	539956.00	180439.73	5.15
NITBH09D	539954.54	180439.04	5.14
NITBH09E	539948.77	180434.30	5.22
NITBH09F	539949.18	180434.77	5.22
NITBH01A	539948.55	180443.13	5.29
NITBH01	539953.33	180444.87	5.28
NITTP05	539947.94	180448.23	5.41
NITBH07	539947.14	180449.86	5.43
NITBH04	539943.82	180446.50	5.39
NITBH04X	539943.82	180446.51	5.38
NITBH08	539931.78	180444.77	5.55
NITTP8	539932.22	180442.01	5.51
NITTP07	539935.04	180437.22	5.41
NT			
NTTP03A	539864.83	180255.08	5.09
NTTP03	539861.05	180252.00	5.10
NTBH02	539850.35	180286.36	5.16
NTTP04A	539839.75	180289.65	5.15
NTTP04	539838.85	180288.11	5.12
NTDS01	539906.01	180349.48	2.66
NTDS02	539918.06	180300.72	2.72
NTBH01*	539868.52	180300.77	2.76
NTBH03**	539869.01	180300.01	2.75
ST			
STBH01	539655.23	179973.19	-8.72
STBH04	539597.20	179927.28	-3.88
STBH02	539603.46	179994.39	-5.88
STBH03	539656.99	179834.86	-4.08
SS			
SSDS04	539478.67	179745.07	5.05
SSDS03	539486.27	179791.10	5.14
SSBH03*	539507.18	179793.44	5.34
SSBH01	539527.90	179815.24	5.56
SSBH01B	539530.52	179811.84	5.64
SSBH01C**	539535.75	179817.14	5.72
SSDS02	539521.13	179780.75	5.74

SSBH02D	539513.84	179759.81	5.31
SSBH02C	539522.27	179770.42	5.50
SSBH02	539526.13	179772.51	5.54
SSBH02B	539529.00	179774.72	5.55
TU			
TUBH01	539879.91	180166.61	-4.89
TUBH02	539709.58	179986.13	-10.04

** Boreholes monitored by Quarternary Scientific in the field*
*** Retrieved geoarchaeological boreholes*

Geoarchaeological borehole retrieval

Following completion of the geotechnical borehole monitoring, two boreholes from the north and south bank of the River Thames were selected for further laboratory-based palaeoenvironmental investigations adjacent to boreholes NTBH01 and SSBH03 (<NTBH03> and <SSBH1C>). These boreholes were specifically chosen as they contained significant thicknesses of Holocene alluvium and peat. This transect provides the potential to identify evidence of change or continuity through time and to establish whether any significant spatial variability exists on either side of the River in this area of the floodplain. U100 core samples were retrieved by Soil Mechanics Limited with a cable percussion rig. At each location, the boreholes extended down to the Gravel. All samples were wrapped and labelled with the depth and orientation, and returned to the University of Reading for cold storage.

Detailed laboratory-based lithostratigraphic descriptions

The retrieved boreholes were recorded in the laboratory using standard procedures for recording unconsolidated sediment and peat, noting the physical properties (colour), composition (gravel, sand, clay, silt and organic matter), peat humification and inclusions (e.g. artefacts) (Troels-Smith, 1955). The procedure involved: (1) cleaning the samples with a spatula or scalpel blade and distilled water to remove surface contaminants; (2) recording the physical properties, most notably colour using a Munsell Soil Colour Chart, but occasionally dryness; (3) recording the composition, including moss peat (Turfa bryophytica; Tb), wood peat (Turfa lignosa; Tl), herbaceous peat (Turfa herbacea; Th), completely disintegrated organic matter (Substantia humosa; Sh), gravel (Grana glareosa; Gg), fine sand (Grana arenosa; Ga), silt (Argilla granosa; Ag) and clay (Argilla steatoides); (4) recording the degree of peat humification, and (5) recording the boundary changes e.g. sharp or diffuse. The results of the laboratory-based descriptions are provided in Tables 7 and 8, Figure 6.

Deposit modelling

In the preparation of the deposit model, 153 borehole and test pit logs were examined from an area centred on NGR TQ 3975 8010. Logs were obtained from British Geological Survey archives (97) and from various drilling campaigns specifically associated with the investigation of the Cable Car site (56), including the two palaeoenvironmental boreholes (<NTBH03> and <SSBH1C>) (see Table 1, Appendix 1 and Figure 3 for details). To develop the deposit model, 36 borehole logs were selected to form a transect extending from NGR TQ 39860 79560 on the south side of the river to NGR TQ 40170 80720 on the north side of the river (selected boreholes are displayed in Figure 4). Thirteen of the boreholes are located on the south side of the river, including palaeoenvironmental borehole <NTBH03>, 7 within the river channel and 16 on the north side of the river, including palaeoenvironmental borehole <SSBH1C>. The criteria for inclusion in the deposit model were (a) proximity to the transect line; and (b) borehole penetration through the full sequence of surviving Holocene alluvial deposits. In practice all but three of the selected boreholes extend down to the bedrock London Clay.

Despite the care taken in the evaluation and selection of the records incorporated in the deposit model, the reliability of the model is affected by the quality of the stratigraphic records which in turn is affected by the nature of the sediments and/or their post-depositional disturbance during previous stages of development on the site. In particular, it is important to recognise that several separate sets of boreholes are represented, put down at different times, by different companies and recorded using different descriptive terms, and subject to differing technical constraints in terms of recorded detail, including the exact levels of the stratigraphic boundaries. The two palaeoenvironmental boreholes described below represent the most detailed record of the Holocene sediment sequence for which accurate height and lithostratigraphic information are available.

In general in the borehole logs it is possible to recognise consistently up to four Holocene sediment units forming Units 3-5 in the present account:

(Unit 6) Made Ground
(Unit 5) Upper Alluvial Silts & Clays
(Unit 4) Peat
(Unit 3) Lower Alluvial Deposits
(Unit 3b) Silts & Clays
(Unit 3a) Sands
(Unit 2) Sand & Gravel (Shepperton Gravel)
(Unit 1) London Clay

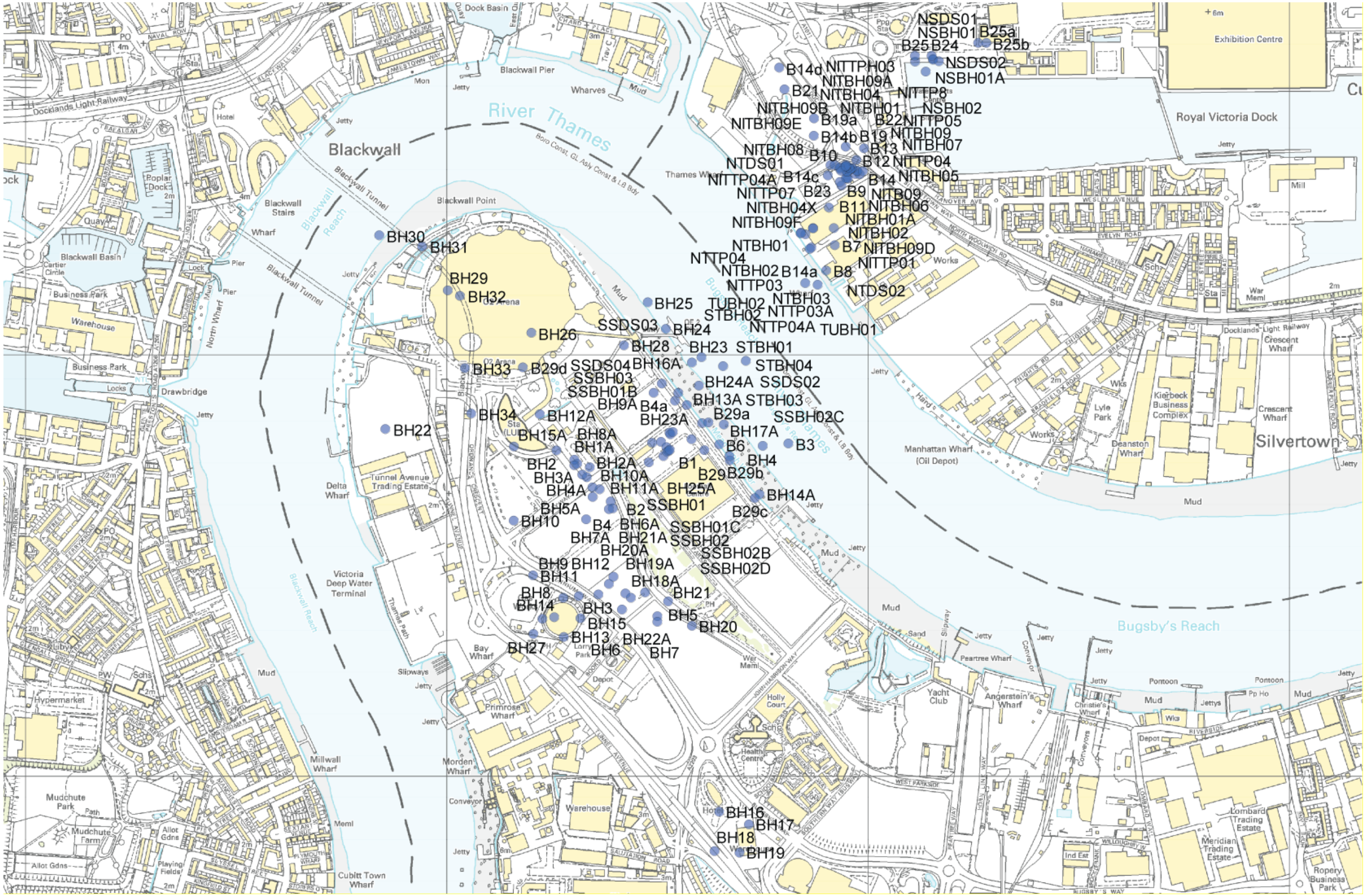

Figure 3: All geotechnical and BGS borehole locations from the Cable Car route and surrounding areas

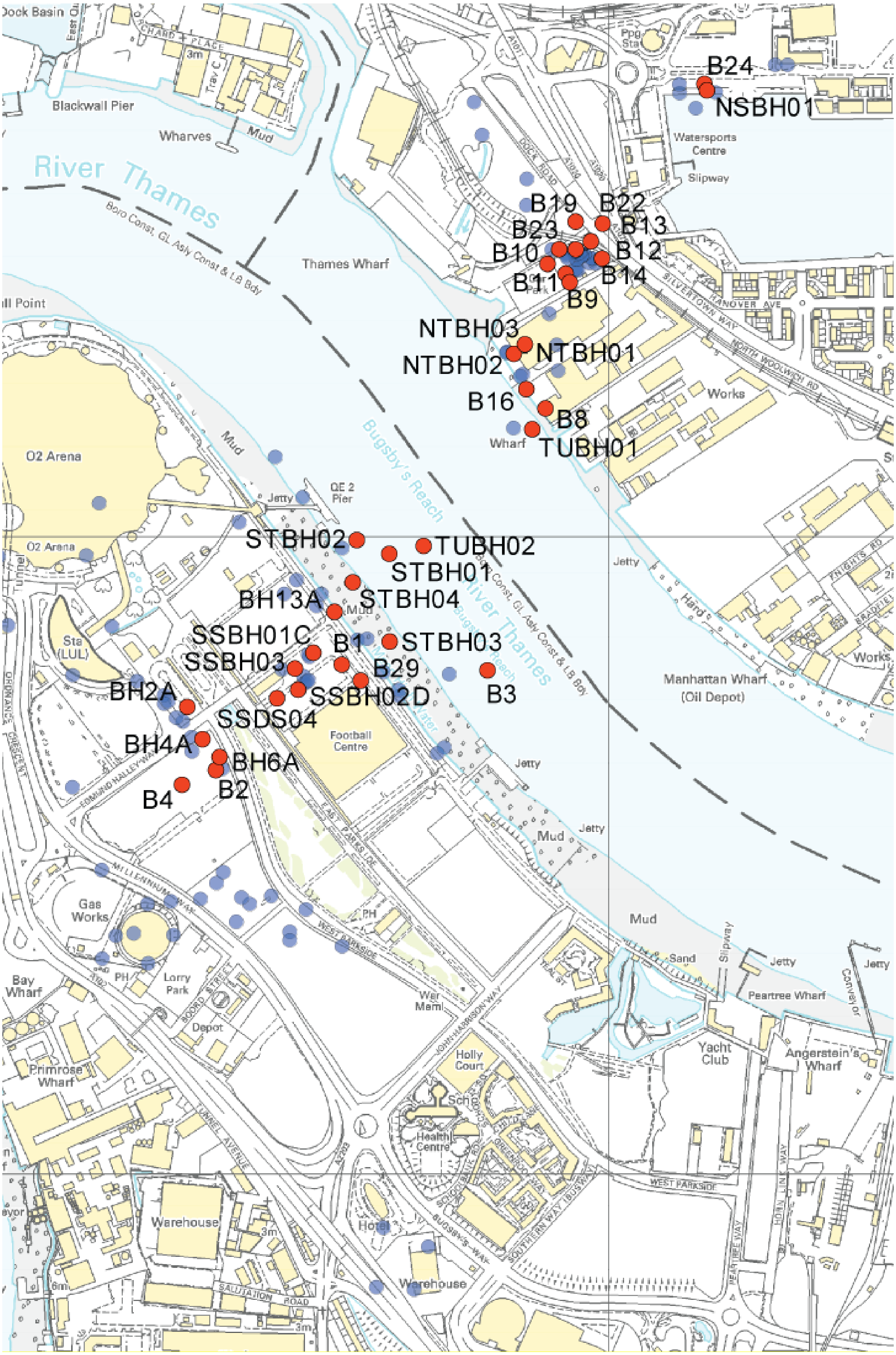

Figure 4: Transect map of selected boreholes along the Cable Car route, London Boroughs of Newham and Greenwich (site code: CAB11). (see Figure 5)

RESULTS AND INTERPRETATION OF THE LITHOSTRATIGRAPHIC DESCRIPTIONS AND DEPOSIT MODELLING

The results of the fieldwork monitoring are displayed in Tables 2 to 5. In the borehole monitored within the North Station (NSBH01; Table 2), Made Ground was recorded down to a depth of -3.25m OD followed by blue-grey alluvium with dark brown pockets of peat and including fragments of wood. Sands and gravels commenced below -4.80m OD. The borehole within the North Intermediate Tower (NITBH02; Table 3), was monitored down to a depth of 10m and was still within Made Ground. No further monitoring was carried out on this borehole, although the geotechnical borehole log, indicate that the Made Ground continued to a depth of 14.50m before reaching London Clay. The borehole from the North Tower (<NTBH01>; Table 4) contained a very small amount of Made Ground (1.20m) overlying a thick sequence of alluvium including two substantial horizons of wood peat. Sands and gravels were encountered at -5.84m OD. This sequence was selected for further laboratory-based palaeoenvironmental investigations, and was re-cored as borehole <NTBH03> (a detailed description of which is provided in Table 6 and Figure 6). The borehole from the South Station (SSBH03; Table 5) contained a thick horizon of contaminated Made Ground (5.20m) overlying alluvium from 0.14m OD and peat from -0.86 to -2.81m OD. Sands and Gravels were recorded below this. As a result of this *ca*. 2m thick horizon of peat, neighbouring borehole location <SSBH1C> was selected for laboratory based palaeoenvironmental investigations (displayed in Table 7 and Figure 6). As outlined within the methodology, these records were integrated with other geotechnical records to provide the following model of depositional history (Figure 5).

The London Clay bedrock (Unit 1) was recorded in 27 of the boreholes. It slopes down evenly on the south side of the river from -8.86m OD in borehole B4 to a maximum depth of -18.8m OD in the middle of the Thames channel in borehole B3, rising within the channel on its north side in borehole N11 to -8.39m OD. On the north side of the river the bedrock surface is uneven between -6.37m OD in borehole B8 and -8.72m OD in borehole B13.

The Shepperton Gravel (Unit 2) was recorded in all but one of the boreholes. On the south side of the river the surface of the gravel is rather uniformly between -2.25m OD (borehole 6a) and -3.45m (borehole 13a). It falls to -5.0m OD in borehole B1, but the gravel in borehole B1 is overlain by 3 feet (0.99m) of sand with a surface at -4.0m OD, and this sand may be part of the Shepperton Gravel rather than part of the overlying Holocene deposits. Within the river channel the gravel surface is at lower levels from *ca*. -5.0m OD (borehole N11) to just below -10.0m OD in the middle of the channel in borehole N12.

On the north side of the river the gravel has been heavily truncated in the seven boreholes in the vicinity of the Royal Victoria Dock. In six of the remaining nine boreholes on the north side of the river, the surface of the gravel, between -4.4m OD (borehole B24) and -5.88m OD (borehole BH03), is generally lower than it is on the south side of the river by about 2m. This difference resembles the situation recorded by Gibbard (1994, Fig.41) in a transect extending from the Greenwich area across the Thames into the Isle of Dogs. This transect shows the surface of the Shepperton Gravel in the Isle of Dogs, on the north side of the river, at least 2m below the level on the Greenwich side of the river. However in the present area of investigation there are two boreholes on the north side of the river (boreholes B19 and B22) in which the surface of the Shepperton gravel is recorded at about the same level as it occurs on the south side of the river – between -2.5m OD and -3.0m OD, and in borehole B8 the surface of the gravel is recorded at +1.55m OD. This suggests the presence here of a gravel 'high', broadly comparable in terms of elevation to the Bermondsey and Horseleydown gravel 'highs' (eyots) upstream in the Southwark area. These variations in the level of the surface of the Shepperton Gravel are consistent with observations elsewhere in the Thames valley. They indicate that at the beginning of the Holocene, the surface of the Shepperton Gravel formed the valley floor of the River Thames and was characterised by gravel bars generally elongated approximately parallel with the valley axis and separated by channels in which finer-grained sediments are often preserved. The relief on this surface is generally from 2.0m to 4.0m and exceptionally up to 6m.

Overlying the Shepperton Gravel in all the boreholes is a sequence of Holocene alluvial deposits. In 18 of the boreholes this sequence includes a peat unit (Unit 4). In six cases (boreholes SSBH02D, SSBH03, B29a, B8, SSDS04, NSBH01) the peat rests directly on the underlying gravel. In the remaining twelve boreholes the peat rests on the Lower Alluvium (Unit 3), either on sand (Unit 3a) (8 boreholes) or on alluvial silts and clays (Unit 3b) (4 boreholes). The Lower Alluvium, whether sand or silts and clays, is generally less than a metre thick (median value 0.6m). In borehole <NTBH03> the Lower Alluvium was a well-bedded tufa-rich sand with common detrital plant and mollusc remains.

Where peat is present it usually forms a single horizon varying in thickness from 2.43m in borehole NTBH02 on the north side of the river to 0.92m in borehole B4 on the south side (average for 11 boreholes with a single untruncated peat horizon: 1.60m, median 1.53m). The upper surface of these untruncated single peat horizons is at levels between -0.66m OD and -3.0m OD (average 1.06m, median 0.98m). The lowest level at which these single peat units are recorded is -4.84m OD in borehole NTBH02. In four boreholes, all on the north side of the river (B8, NTBH01, <NTBH03>, B24) two peat horizons are present. Two of these boreholes (NTBH01 and <NTBH03>) were immediately adjacent to one another and recorded closely similar alluvial sequences with a lower peat between -4.74m OD and -5.84m OD in Borehole NTBH01 and peat at a similar level in <NTBH03>. The greater part of this lower peat is therefore at a level below the lowest level at which the base of the single peat horizons was encountered. The upper surface of the upper peats in these two boreholes is close to -1.4m OD and therefore close to the level of the upper surface of the single peat horizons.

In borehole B24 a lower peat horizon occupies a level (-1.6 to -4.0m OD) similar to the single peat horizons recorded elsewhere in the transect, but the Holocene sequence in borehole B24 includes an upper peat at a higher level, between +2.9m OD and +0.8m OD. Peat is also recorded in borehole B8 at a similar level where two thin peat horizons are present between +3.37m OD and +1.55m OD.

In the 11 boreholes with untruncated peat horizons and in all four of the boreholes with two peat horizons, the uppermost peat is overlain by the Upper Alluvium (Unit 5). Where this unit has been examined in detail in boreholes <SSBH01C> and <NTBH03>, it is a grey to olive coloured well-sorted silt with some evidence of soil forming processes in its upper part and scattered finely-divided detrital plant remains generally present. It is everywhere overlain by Made Ground and has undoubtedly been truncated in some places. However in fourteen boreholes the contact with the Made Ground is at a level between 3.33m OD (Borehole 13a) and 0.57m OD (Borehole BH01C) (Average 1.77m OD, median 1.70m OD). A natural floodplain level close to 1.75m OD therefore seems likely.

Table 2: Results of the field-based lithostratigraphic description of borehole NSBH01, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Depth (m BGS)	Composition
4.85 to -3.25	0 to 8.10	Made Ground
-3.25 to -4.80	8.10 to 9.65	Blue-grey silty clay (alluvium) with dark brown pockets of peat and including fragments of wood (interrupted recovery)
>-4.80	>9.65	Sands and gravels

Table 3: Results of the field-based lithostratigraphic description of borehole NITBH02, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Depth (m BGS)	Composition
5.28 to -4.72	0 to 10+	Made Ground

Table 4: Results of the field-based lithostratigraphic description of borehole NTBH01, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Depth (m BGS)	Composition
2.76 to 1.56	0 to 1.20	Made Ground
1.56 to -1.44	1.20 to 4.20	Blue-grey silty clay (alluvium) with occasional inclusions of waterlogged wood and Mollusca
-1.44 to -3.34	4.20 to 6.10	Dark brown; Well humified wood peat with occasional clay inclusions
-3.34 to 4.74	6.10 to *ca*. 7.50	Blue-grey silty clay (alluvium) with occasional inclusions of waterlogged wood
-4.74 to -5.84	*ca*. 7.50 to 8.60	Dark brown moderately humified peat with wood and herbaceous inclusions, becoming more sandy with depth
>-5.84	>8.60	Sands and gravels

Table 5: Results of the field-based lithostratigraphic description of borehole SSBH03, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Depth (m BGS)	Composition
5.34 to 0.14	0 to 5.20	Contaminated Made Ground
0.14 to -0.86	5.20 to 6.20	Blue-grey silty clay (alluvium) with occasional inclusions of waterlogged wood and Mollusca.
-0.86 to -2.81	6.20 to 8.15	Reddish brown well humified wood peat with inclusions of silt and clay
>-2.81	>8.15	Sands and gravels

Table 5: Results of the laboratory-based lithostratigraphic description of borehole NTBH03, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Sample type	Composition
2.75 to 1.55	-	Made Ground
1.55 to 1.10	U100	2.5Y4/1 dark grey with black flecks; very well sorted silt; massive; common detrital plant remains increasingly common downward; no acid reaction.
1.10 to 1.05	Shoe sample	olive brown silt; common detrital plant remains.
1.05 to 0.10	-	No retrieval
0.10 to 0.05	Shoe sample	Irregular mass of plant-rich silt.
0.05 to -0.40	U100	5Y3/1 very dark grey passing down gradually to 2.5Y4/4

		olive brown, black flecks; very well sorted silt; massive passing down to blocky/crumby; root channels common in lower olive brown part; common root remains; vivianite as small (<1mm) white crystal clusters; strong acid reaction.
-0.40 to -0.45	Shoe sample	grey silt oxidising to olive brown with black flecks.
-0.45 to -0.58	U100	5Y4/1 dark grey and 2.5Y4/4 olive brown; very well sorted silt; blocky/crumby; scattered root channels and root remains; scattered detrital plant remains; moderate acid reaction; well-marked transition to:
-0.58 to -0.90	U100	Gley 1.4/1 dark grey; very well sorted silt; massive; scattered detrital plant remains; no acid reaction.
-0.90 to -0.95	Shoe sample	olive brown silt.
-0.95 to -1.40	U100	Gley 1.4/1 dark grey with Fe staining on structural surfaces; very well sorted silt; massive; scattered detrital plant remains; vivianite as small (<1mm) white crystal clusters and coating some structural surfaces.
-1.40 to -1.45	Shoe sample	grey silt with Fe stained structural surfaces.
-1.45 to -1.90	U100	5Y4/1 dark grey; very well sorted silt; massive; detrital plant remains increasingly common downward; wood debris increasingly common downward; no acid reaction.
-1.90 to -1.95	Shoe sample	peat.
-1.95 to -2.40	U100	Peat with round wood (up to 40mm Ø).
-2.40 to -2.45	Shoe sample	woody peat.
-2.45 to -2.90	U100	Peat with common wood debris.
-2.90 to -3.15	Shoe sample	woody peat.
-2.95 to -3.17	U100	Peat with wood debris; well-marked transition to:
-3.17 to -3.28	U100	Mixture of wood-rich silt and peat in large (80mm) interpenetrating masses; very sharp contact with:
-3.28 to -3.40	U100	5Y4/1 dark grey; silt and silty fine sand; unevenly bedded – alternations of silt and silty fine sand with individual beds 2-3mm thick; root channels with scattered *in situ* vertical root remains; scattered detrital plant remains; moderate acid reaction.
-3.40 to -3.45	Shoe sample	organic silty sand.
-3.45 to -3.90	U100	5Y4/1 dark grey; well sorted silt and fine sand; bedded – alternations of silt and silty fine sand with individual beds varying from 2-10mm thick; root channels with scattered in situ vertical roots; scattered detrital plant remains; small piece of round wood(10mm Ø); weak acid reaction.
-3.90 to -4.15	Shoe sample	organic silty sand.
-3.95 to -4.11	U100	5Y3/2 dark olive grey; well sorted slightly silty fine sand; massive; scattered broken mollusc shell; strong acid reaction; very sharp inclined contact with:
-4.11 to -4.21	U100	Mass of wood - ?root wood; very sharp horizontal contact with:
-4.21 to -4.40	U100	5Y4/1 dark grey; silt and silty fine sand; unevenly bedded - alternations of silt and silty fine sand with individual beds varying from 2-10mm thick; scattered detrital plant remains.
-4.40 to -4.45	Shoe sample	peat
-4.45 to -4.75	U100	Black with white vivianite flecks; well humified peat;

		lenses of blue vivianite; very sharp contact with:
-4.75 to -4.90	U100	5Y4/2 olive grey; fine to medium tufa-rich sand; massive; scattered detrital plant remains; scattered broken mollusc shell; strong acid reaction.
-4.90 to -5.15	Shoe sample	peat
-5.20 to -5.65	-	No retrieval
-5.45 to -5.68	U100	Dark brown to black; wet mixture of peat, silt and wood debris becoming firmer and more sandy downward; gradual transition to:
-5.68 to -5.88	U100	5Y3/1 very dark grey to black; silty fine sand with bed of tufa-rich coarser sand at -5.81- -5.83m OD; horizontally bedded; common detrital plant remains; scattered broken mollusc shell; strong acid reaction; well-marked transition to:
-5.88 to -5.90	U100	Silty sandy gravel
-5.90 to -5.95	Shoe sample	Sandy gravel/gravelly sand.

Table 6: Results of the laboratory-based lithostratigraphic description of borehole <SSBH1C>, London Cable Car London Boroughs of Newham and Greenwich (site code: CAB11)

Depth (m OD)	Sample type	Composition
5.72 to 1.02	-	Made ground
1.02 to 0.77	U100	5Y4/2 olive grey to black with black flecks; well sorted gritty silt; massive; root channels; Charcoal; CBM; coal dust; piece of coke (50mm) at 0.84m OD; no acid reaction; well-marked transition to:
0.77 to 0.57	U100	5Y4/2 olive grey; well sorted silt; coarse bedding with horizontal partings marked by laminated plant material; scattered root channels and root remains; charcoal; CBM; no acid reaction.
0.57 to 0.52	Shoe sample	olive silty clay
0.52 to 0.07	U100	5Y4/2 olive grey with black patches and flecks; very well sorted silt; massive; common Fe-coated root channels and common root remains; faunal burrows; scattered detrital plant remains; moderate acid reaction.
-0.07 to -0.02	Shoe sample	nominal (220mm actual) olive silty clay
-0.02 to -0.43	U100	5Y4/3; very well sorted silt; massive; root channels; no acid reaction; tarry contamination coating structural and other surfaces.
-0.43 to -0.48	Shoe sample	olive silty clay with tarry contamination
-0.48 to -0.93	U100	5Y4/3 olive with black flecks; very well sorted silt becoming slightly peaty below -0.72m OD with wood debris; massive; root channels and scattered root remains; scattered detrital plant remains; no acid reaction; tarry contamination coating structural and other surfaces.
-0.93 to -0.98	Shoe sample	peat with branch wood
-0.98 to -1.43	U100	10YR2/2 very dark brown; peat with common wood debris
-1.43 to -1.48	Shoe sample	peat with branch wood
-1.48 to -1.93	U100	10YR2/2 very dark brown; peat with round wood (up to 35mm Ø).
-1.93 to -1.98	Shoe sample	*missing*

-1.98 to -2.24	U100	10YR2/2 very dark brown; incoherent mixture of peat and round wood (up to 40mm Ø) - ? drilling spoil; sharp contact with:
-2.24 to 2.43	U100	10YR2/2 very dark brown; peat; horizontal laminations.
-2.43 to -2.48	Shoe sample	woody peat with contorted partings of grey silt.
-2.48 to -2.93	U100	5Y3/2 dark olive grey; very well sorted silt with irregular inclusion of peat between -2.68m and -2.81m OD.
-2.93 to -2.98	Shoe sample	dark olive silt with scattered wood debris.
-2.98 to -3.06	U100	Peat with common wood debris; uneven sharp contact with:
-3.06 to -3.27	U100	5Y4/1 dark grey; very well sorted fine sand; no acid reaction; sharp contact with:
-3.27 to -3.43	U100	2.5Y4/4 olive brown; slightly silty sandy gravel of sub-angular and well-rounded flint clasts (up to 40mm).

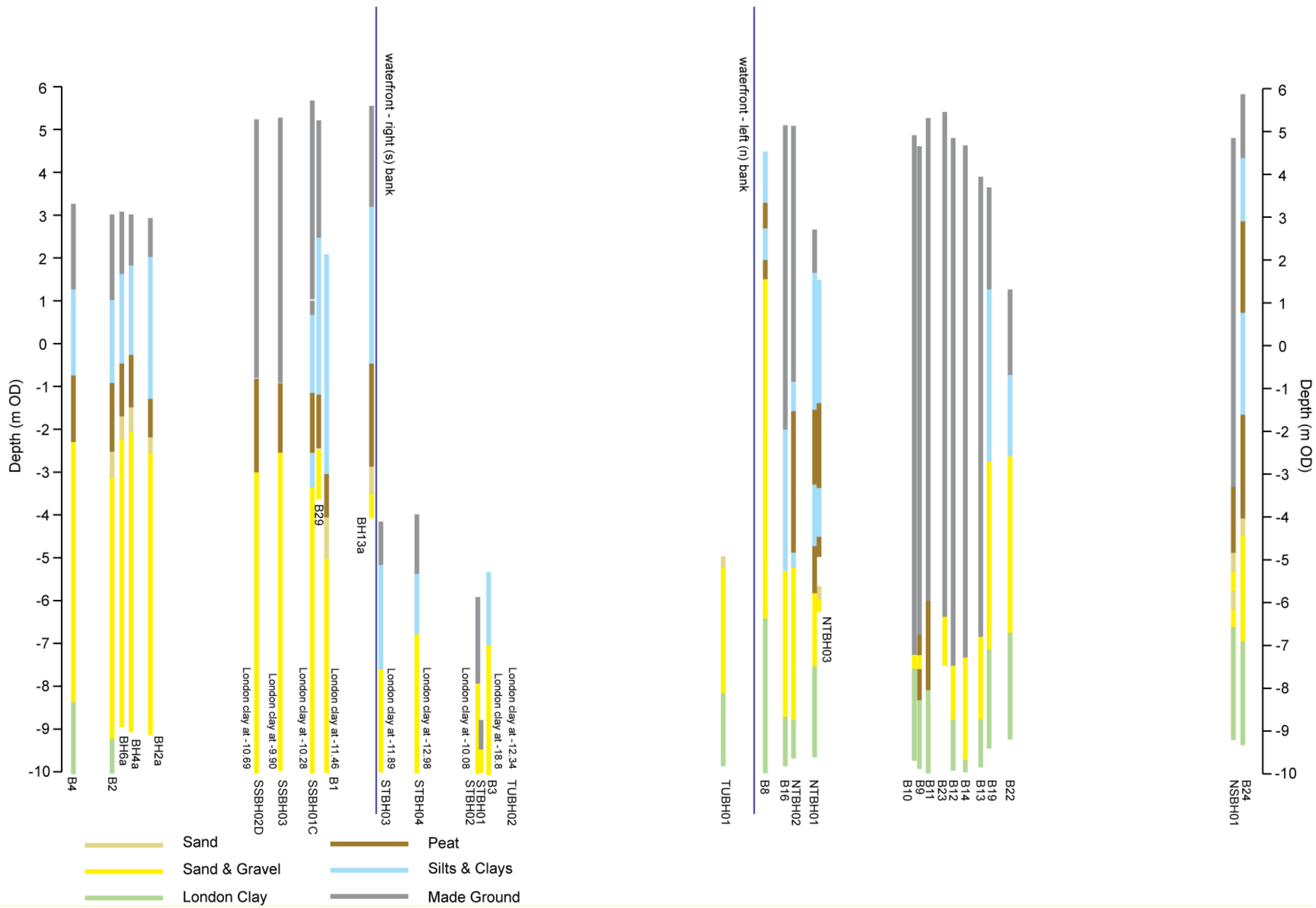

Figure 5: Transect of selected sedimentary logs across the Cable Car route

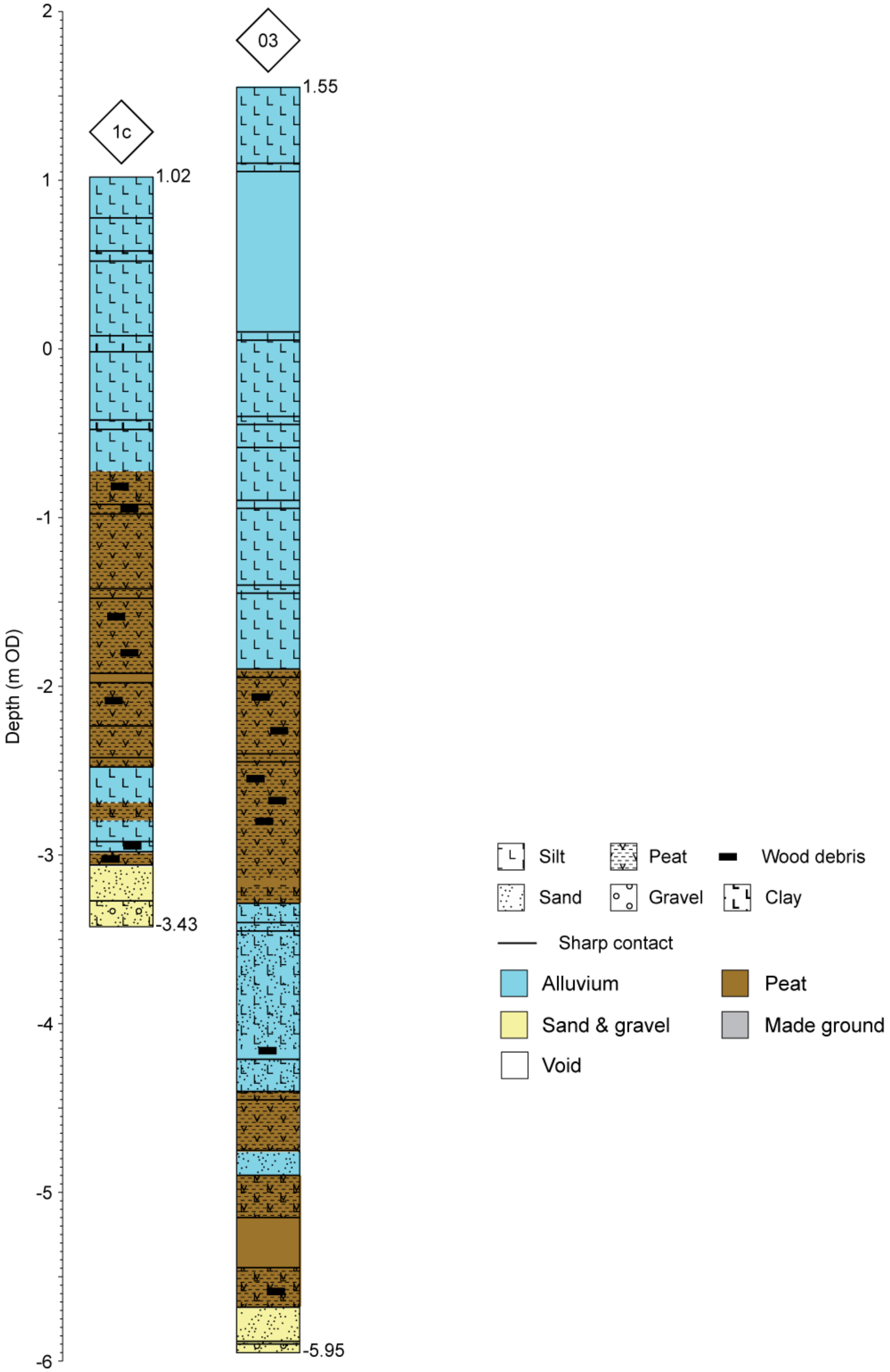

Figure 6: Detailed lithostratigraphy of the selected palaeoenvironmental boreholes

DISCUSSION

The stratigraphic sequences recorded in the boreholes can be understood in terms of six phases of development.

1. Erosion of the bedrock London Clay (Unit 1) by the ancestral River Thames probably during the Late Devensian Late Glacial, creating an uneven surface mainly between -6.0m OD and -9.0m OD, probably reflecting the activity of multiple channels in a braided river system, but involving the deepening of a master channel down to at least -18.8m OD beneath the site of the present river.
2. Deposition of sand and gravel in a Late Devensian Late Glacial braided river system, forming the Shepperton Gravel (Unit 2) and creating during the final stages of deposition a topographic surface characterised by longitudinal gravel bars aligned approximately parallel to the valley axis and separated by linear depressions marking the position of low water channels. This surface with a relief of between *ca*. 2.0m and *ca*. 6.0m formed the valley floor of the River Thames at the beginning of the Holocene. Gravel bars appear to be represented at the present site in the sediment sequence recorded in borehole B8, and possibly at a lower level in boreholes B19 and B22.
3. An important development in the early part of the Holocene was the transformation of the River Thames from a braided river system to a single channel meandering river, although subsidiary channels were undoubtedly maintained in some of the deeper inter-bar depressions. Deposition at this stage was mainly in the form of sands, silts and clays (Unit 3), often richly organic, as observed in borehole <NTBH03>. The present channel of the River Thames appears to have been established at this time and there is no evidence that it has shifted its position significantly during much of the Holocene. The bed of the channel forms a depression in the Shepperton Gravel and the gravel is overlain by a thin (1-2m) layer of fine-grained sediments which are probably subject to active re-arrangement by the modern river.
4. Although phases of peat accumulation are recorded in various places on the valley floor of the Thames from early in the Holocene, the onset of the main phase of peat accumulation in the reach of the Thames being described here, appears to have taken place in the fifth millennium BC and peat accumulation (Unit 4) continued for up to 3,000 years. In most places, including most of the boreholes recorded in the deposit model, a single peat horizon was created at this time but sequences recording more than one peat horizon are not uncommon in the Thames valley and are represented at this locality in boreholes NTBH01 and <NTBH03>.
5. As a consequence of rising sea level in the second millennium BC, the valley floor of the lower Thames became increasingly susceptible to inundation by estuarine floodwater and widespread peat accumulation ceased. It was succeeded in most places by deposition of silts and clays (Unit 5) which also reflect increasing sediment availability brought about by

soil erosion associated with the intensification of agricultural land-use in the later prehistoric period and continuing into the historic period. The accumulation of these sediments progressively subdued the topographic diversity of the valley floor, leaving only the most elevated gravel bars upstanding above the general level of the floodplain. Peat formation continued during this period, but only in localised depressions and particularly around the margins of the upstanding gravel 'islands'. These conditions appear to be represented at the present site by the sediment sequence recorded in borehole B8 and probably also in borehole B24.

6. From the 17th century onward and particularly in the 19th and 20th centuries, the whole of the area forming the subject of this investigation has been developed for commercial and industrial purposes, involving deep excavations to form the docks on the north side of the river and widespread land-raising throughout the area with deposition of substantial thicknesses of Made Ground. Of the 62 boreholes and test pits put down during the investigation of the London Cable Car site, 48, including all of those put down around the proposed site of the North Intermediate Tower, terminated downward in Made Ground.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, these investigations contribute important new insights to an understanding of Holocene palaeoenvironments in this part of the Thames valley, complementing previous research around the Royal Docks and adding substantially to the record in the North Greenwich peninsula. There is therefore a strong case for taking the investigation forward to allow a more detailed examination of the palaeoenvironmental evidence. It is therefore recommended that a detailed assessment of the two collected boreholes is undertaken, incorporating rangefinder radiocarbon dates, and pollen, diatom, waterlogged plant macrofossil (seeds and wood), insect and Mollusca investigations.

REFERENCES

Batchelor, C.R. (2009) *Middle Holocene environmental changes and the history of yew (Taxus baccata L.) woodland in the Lower Thames Valley*. Unpublished PhD thesis, University of London

Branch, N.P., Green, C.P., Vaughan-Williams, A., Elias, S., Swindle, G., & Batchelor, C.R. (2005) Bellot Street, Maze Hill, London Borough of Greenwich (site code: GBL05): environmental archaeological assessment. ArchaeoScape Unpublished Report.

Branch, N.P., Batchelor, C.R., Elias, S., Green., C.P. & Swindle, G.E. (2007) *Preston Road, Poplar High Street, Poplar, London Borough of Hamlets (site code: PPP06): environmental archaeological analysis*. ArchaeoScape Unpublished Report.

Carew, T., Meddens, F., Batchelor, R., Branch, N., Elias, S., Goodburn, D., Vaughan-Williams, A., Webster, L. & Yeomans, L. (2009) human-Environmental interactions at the wetland edge in East London: trackways, platforms and Bronze Age responses to environmental change. *London and Middlesex Archaeology Society*, **6**: 1-34.3.

Divers, D. (1995) *Archaeological Excavation of the former Beckton Nursery*. Newham Museum Service Unpublished Report.

Gifford & Partners Ltd. (2001) *A13 Thames Gateway Phase III Archaeological Works: Freemasons Road Underpass Assessment Report on Detailed Excavation*. Gifford Unpublished Report.

Holder, N. (1998) *An Archaeological Excavation Assessment and Updated Project Design for Royal Docks Community School Site, Prince Regent Lane, Newham.* MoLAS Unpublished Report.

Jarrett, C. (1996) *Archaeological evaluation at the East Beckton District Centre*. Newham Museum Service Unpublished Report.

Lakin, D. (1998) *Atlas Wharf, Westferry Road, Isle of Dogs*. MoLAS unpublished report.

McLean. G. (1993) *An outline report on an archaeological evaluation at the land at the rear of 72-88 Bellot Street Greenwich London SE10*. SELAU Unpublished Report.

Meddens, F.M. & Beasley, M. (1990) Wetland use in Rainham, Essex. *London Archaeologist,* **6**, 9.

Morley, M. (2003) *Greenwich Industrial Estate, Bugsby's Way, Charlton, London SE7, a Geoarchaeological Investigation*. MoLAS Unpublished Report.

Pepys, S. (1665). *Samuel Pepys Diary September 1665*. Available at http://www.pepysinfo/1665/ 1665sep.html accessed on 20th April 2007.

Philp, B. (1993) *An Outline Report on an Archaeological Evaluation Excavation at the Land at the Rear of 72-88 Bellot Street, Greenwich, London SE10*. SELAU Unpublished Report.

Scaife, R.G. (2001) *East Ham FC, Pennyroyal Avenue, Beckton, London E6, an Environmental Assessment*. Unpublished HAT Report 903.

Sidell, E.J. (2003) *Relative sea-level change and archaeology in the inner Thames estuary during the Holocene.* University College, London, Unpublished PhD Thesis.

Spurr, G., Scaife, R., Cameron, N. & Corcoran, J. (2001) *145-155 Albert Road, E16 London Borough of Newham: a geoarchaeological evaluation report*. MoLAS Unpublished Report.

Spurrell, F.C.J. (1889) On the Estuary of the Thames and its alluvium. *Proceedings of the Geologists' Association,* **11**, 210-230.

Tamblyn, W.S. (1994) *Archaeological evaluation of Beckton areas A and B Tollgate Road, Beckton, London Borough of Newham*. Newham Museum Service Unpublished Report.

Tucker, S. (1993) *Salter Road and Rotherhithe Street, London SE16*. MoLAS: Unpublished Report.

Truckle, N. (1996) *Recent excavations on wetland sites in Beckton: A publication progress report*. Newham Museum Service Unpublished Report.

Truckle, N. & Sabel, K. (1994) Beckton Alps Ski Slope, Newham Way, East Ham E6, London Borough of Newham. Newham Museum Service Unpublished Report.

Wessex Archaeology (2000) *Fort Street (West) Silvertown, London, E16, Archaeological excavation assessment report*. Wessex Archaeology: Unpublished Report.

Wilkinson, K.N., Scaife, R.J. & Sidell, E.J. (2000) Environmental and sea-level changes in London from 10,500 BP to the present: a case study from Silvertown. *Proceedings of the Geologists' Association,* **111**, 41-54.

APPENDIX 1: ADDITIONAL BOREHOLE LOCATIONS

Record name	Origin	Easting	Northing
BH2	SE Gas mains	539260	179773
BH3	SE Gas mains	539359	179432
BH4	SE Gas mains	539749	179784
BH5	SE Gas mains	539525	179415
BH6	SE Gas mains	539415	179396
BH7	SE Gas mains	539499	179380
BH8	SE Gas mains	539254	179378
BH9	SE Gas mains	539313	179428
BH10	SE Gas mains	539158	179607
BH11	SE Gas mains	539204	179477
BH12	SE Gas mains	539276	179424
BH13	SE Gas mains	539277	179331
BH14	SE Gas mains	539226	179374
BH15	SE Gas mains	539317	179375
BH16	SE Gas mains	539646	178916
BH17	SE Gas mains	539716	178886
BH18	SE Gas mains	539635	178823
BH19	SE Gas mains	539694	178819
BH20	SE Gas mains	539581	179357
BH21	SE Gas mains	539470	179436
BH22	SE Gas mains	538853	179824
BH23	SE Gas mains	539581	179982
BH24	SE Gas mains	539519	180062
BH25	SE Gas mains	539476	180125
BH26	SE Gas mains	539200	180052
BH27	SE Gas mains	539205	179338
BH28	SE Gas mains	539420	180023
BH29	SE Gas mains	539002	180153
BH30	SE Gas mains	538839	180284
BH31	SE Gas mains	538941	180257
BH32	SE Gas mains	539031	180140
BH33	SE Gas mains	539042	179969
BH34	SE Gas mains	539057	179861
BH1A	SE Gas mains	539309	179742
BH2A	SE Gas mains	539339	179733
BH3A	SE Gas mains	539332	179710
BH4A	SE Gas mains	539362	179681
BH5A	SE Gas mains	539346	179663
BH6A	SE Gas mains	539389	179652
BH7A	SE Gas mains	539393	179636
BH8A	SE Gas mains	539302	179751
BH9A	SE Gas mains	539302	179738
BH10A	SE Gas mains	539321	179716
BH11A	SE Gas mains	539345	179686
BH12A	SE Gas mains	539220	179859
BH13A	SE Gas mains	539569	179881
BH14A	SE Gas mains	539741	179669
BH15A	SE Gas mains	539159	179783
BH16A	SE Gas mains	539510	179932

BH17A	SE Gas mains	539671	179750
BH18A	SE Gas mains	539436	179424
BH19A	SE Gas mains	539423	179434
BH20A	SE Gas mains	539384	179457
BH21A	SE Gas mains	539395	179474
BH22A	SE Gas mains	539499	179367
BH23A	SE Gas mains	539541	179891
BH24A	SE Gas mains	539549	179910
BH25A	SE Gas mains	539605	179838
B1.	BGS	539580	179800
B29	BGS	539611	179774
B29a	BGS	539620	179840
B29b	BGS	539670	179760
B29c	BGS	539730	179660
B29d	BGS	539180	179970
B2	BGS	539384	179634
B3	BGS	539810	179790
B4	BGS	539330	179610
B4a	BGS	539490	179910
B6	BGS	539646	179787
B7	BGS	539920	180260
B8	BGS	539900	180200
B9	BGS	539936	180402
B10	BGS	539904	180426
B11	BGS	539932	180410
B12	BGS	539946	180448
B13	BGS	539971	180463
B14	BGS	539987	180436
B14a	BGS	539850	180170
B14b	BGS	539870	180520
B14c	BGS	539910	180450
B14d	BGS	539788	180682
B16	BGS	539870	180230
B19	BGS	539946	180494
B19a	BGS	539871	180561
B21	BGS	539801	180630
B22	BGS	539990	180490
B23	BGS	539920	180450
B24	BGS	540150	180710
B25	BGS	540110	180710
B25a	BGS	540260	180740
B25b	BGS	540280	180740