ARCA Geoarchaeology

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LONG REACH STW, DARTFORD, KENT: PALAEOENVIRONMENTAL ANALYSIS

Prepared for:
AECOM

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SUMMARY

An assessment ('Phase 1') of three geoarchaeological boreholes and 57 geotechnical boreholes drilled at Long Reach, Dartford, in 2010 demonstrated that strata of moderate to high palaeoenvironmental potential existed throughout the site within the Holocene sedimentary sequence. As a result a programme of bio- and geoarchaeological assessment ('Phase 2') was carried out by ARCA and Quaternary Scientific (Quest) between January and June 2012. The work focussed on cores recovered from two of the geoarchaeological boreholes drilled during the Phase 1 assessment and comprised mass specific magnetic susceptibility, palynological and diatom assessment and AMS ^{14}C dating. Following the Phase 2 works, and an additional geoarchaeological watching brief on further geotechnical boreholes, recommendations for a final analytical phase of works ('Phase 3') were made.

The Phase 3 works reported here comprised the drilling of three additional geoarchaeological boreholes, the production of updated deposit models for the site, AMS ^{14}C dating of organic strata from to boreholes, and a programme of bioarchaeological assessment (ARCA BH6) and analysis (ARCA BH8) of pollen, diatom and waterlogged wood remains.

Deposit modelling at the site enabled the production of updated surface elevation and thickness models for the main sedimentary units encountered at Long Reach. The sedimentary sequence at the site consisted of four main stratigraphic units: at the base, bedrock of the undifferentiated Newhaven and Seaford Formations (Upper Chalk) outcropped at between -5.00m OD and -14.50m OD, sloping down towards the north; overlying the Chalk, deposits of sands and gravels of the Shepperton Member were encountered which were in turn overlain by strata of the Holocene Tilbury Member and finally Made Ground.

Tilbury Member strata at Long Reach thickened towards the north and were comprised of a sequence of three sedimentary units: the lower fine-grained mineral bed (LFGMB), middle organic bed (MOB), and the upper fine-grained mineral bed (UFGMB).

Organic strata within the LFGMB were ^{14}C dated to the Mesolithic period (7400-7200 cal BP). ^{14}C dating also demonstrated that the MOB formed from the Early Neolithic until the post-Roman period (1560-1410 cal BP). The MOB initially formed in an emergent saltmarsh environment, which was succeeded by freshwater carr and then by further reed peats and mineral intertidal strata. The

UFGMB comprised mineral strata deposited in a subsequent mudflat environment overlain by a further reed peat dating to the Early Medieval period (1270-1090 cal BP).

Palynological investigations throughout the MOB provided evidence for a series of vegetation shifts both on the wetland and the surrounding dryland areas likely to have been the result of a number of human (e.g. Bronze Age woodland clearance and cultivation) and natural (e.g. changes in relative sea level) factors. Diatom analysis of ARCA BH8 meanwhile provided evidence for a general increase in saline influence in the upper part of the MOB from the Bronze Age onwards.

Although only indirect evidence for human activity has been found as a result of the geoarchaeological and palaeoenvironmental studies carried out at Long Reach, Dartford, the project has provided information of considerable palaeoenvironmental significance. The site provides a detailed Holocene sea level and palaeobotanical record in a part of the Lower Thames where investigations have previously been sparse. Consequently publication of the data reported here will contribute significantly to the understanding of the Holocene evolution of the Lower Thames.

1. INTRODUCTION

1.1 A series of geoarchaeological works at Long Reach Sewerage Treatment Works (STW) (henceforth 'the site') carried out between 2010 and 2013 demonstrated the presence of strata of high palaeoenvironmental potential at the site. The geoarchaeological works were conducted at the request of Thames Water in advance of the construction of new sewerage treatment facilities. The overall geoarchaeological project was carried out in accordance with a brief produced by Kent County Council (KCC) (2009), while the work reported here was carried out on behalf of AECOM. The first stage of the project ('Phase 1') involved a geoarchaeological assessment of the site based on examination of 57 existing logs from previous geotechnical boreholes and of strata recovered in three geoarchaeological boreholes (Wilkinson 2012). Phase 2 works comprised a palaeoenvironmental assessment of cores from two of the geoarchaeological boreholes (Wilkinson *et al.* 2012). On the basis of recommendations arising from the Phase 2 works, geoarchaeological monitoring of geotechnical boreholes was carried out (Wilkinson 2013a). Following the watching brief, recommendations for a further phase ('Phase 3') of works were made. A written scheme of investigation was prepared in response to the latter in accordance with which the present works were carried out (Wilkinson 2013b). ARCA were therefore commissioned by AECOM to carry out a further programme of geoarchaeological and palaeoenvironmental analyses. ARCA in turn sub-contracted Quaternary Scientific (Quest) of the University of Reading to undertake the majority of the bioarchaeological works. Fieldwork was carried out during autumn 2013 and the analytical programme was completed in June 2014.

1.2 This report presents the results of a geoarchaeological assessment carried out on three boreholes drilled by Quest/ARCA during the Phase 3 works (ARCA BH6, BH7 and BH8), and palaeoenvironmental analysis and assessment carried out on two sequences (ARCA BH6 and ARCA BH8). This report is intended to be read alongside the reporting from the earlier stages of geoarchaeological and palaeoenvironmental works (Wilkinson 2012, Wilkinson *et al.* 2013, Wilkinson 2013) and as such only a summary of the project background is provided. Following a brief discussion of the context of the site and previous works upon it, an account is given of the field and laboratory methods that have been utilised during the Phase 3 works. The methodology is followed by a detailed discussion of the stratigraphy encountered in the three new boreholes drilled as part of the present works. The ^{14}C chronology of ARCA BH6 and ARCA BH8 is then presented followed by a discussion of the results of the palaeoenvironmental analyses carried out on cores from the same boreholes. An outline of the overall site stratigraphy is then given incorporating new stratigraphic data from the Phase 3 boreholes into updated stratigraphic models for the site. Following this, the implications of the litho-, bio- and chronostratigraphic dataset for the Stage 3 objectives (Section 1.6) are then considered. A conclusion in which the importance of the site and the works conducted upon it are considered completes the main body of the report. A bibliography and appendices containing the original lithostratigraphic and bioarchaeological data from the Phase 3 works are provided at the end of the report.

1.3 The Long Reach Sewerage Treatment Works is centred on NGR TQ 5533 7675 and covers an area of 29 ha (Hallybone 2008). Several areas of Long Reach were proposed for upgrade and these are mostly located in the southern part of the site (see Figure 1). Long Reach sits 3.5 km to the north-east of the town of Dartford and immediately west of the Littlebrook Power Station. The northern boundary of the site is formed by the south bank of the River Thames, while the River Darent, a south bank tributary of the Thames meets the latter river 500m north-west of the site. The site is located on the present Thames floodplain at an elevation of *c.* +1–3 OD.

1.4 The British Geological Survey (BGS) (1998) map the site as lying on 'made ground (undivided)', indicating that the surficial layers are composed of deliberately deposited sediment placed on the site by people, presumably to raise its surface above flood level. The underlying drift geology is mapped as 'alluvium', a catch all term to describe Holocene sediment deposited in fluvial (river) environments. However, as discussed below (Section 3), the 'alluvium' is in practice mostly an intertidal phenomenon (i.e. 'Tidal Flat Deposits' in BGS terminology). The drift units discussed above are mapped as overlying chalk of the undifferentiated Seaford and Newhaven Chalk Formations. Both the latter formations formed during the Upper Cretaceous and date between 89.0 and 71.3 million year (my) BP (BGS 2014).

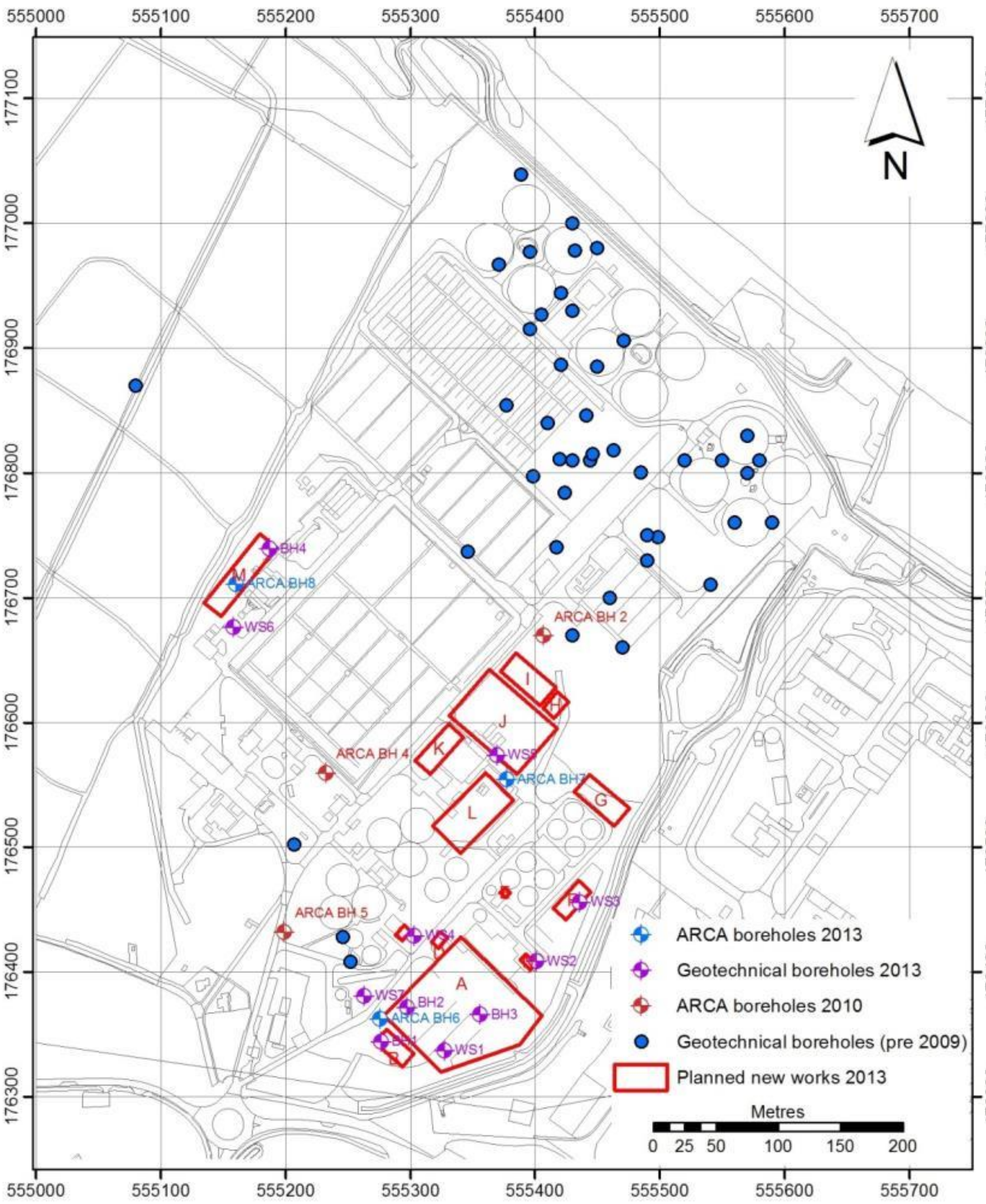

Figure 1: Location of Phase 3 boreholes, Long Reach Sewerage Treatment Works.

1.5 The results of the previous geoarchaeological work demonstrate that the Holocene (11,500 BP to present) stratigraphy thickens from 5.0m in the south of the site to 15.25m in the north. It is comprised of three beds of the Tilbury Member (*sensu* Gibbard 1999). The lowest ('Lower fine-grained mineral bed' [*sensu* Wilkinson 2012]) is dominated by mineral sediments and was prior to the present work thought likely to have formed in the Mesolithic period (9500-4500 cal. BC). The middle bed ('Middle organic bed') is comprised primarily of organic strata, while the uppermost bed ('Upper fine-grained mineral bed') is again of mineral sediments. Made Ground deposits of 1.45-3.60m thickness overlie strata of the Tilbury Member, there being a trend for increasingly thick Made Ground deposits in a north-easterly direction. ^{14}C dating of the Middle organic bed in the western part of the site during the Phase 2 works demonstrates development between the Early Neolithic and Late Romano-British/Sub Roman period (Wilkinson *et al*. 2012). Palynological and diatom studies suggest that the Middle organic bed initially formed in freshwater alder carr and later in open marsh (Wilkinson *et al*. 2012).

1.6 The objectives of the Phase 3 geoarchaeological and palaeoenvironmental analysis reported here were to (Wilkinson 2009, 2013b, 2,):

1.6.1 Provide chronological and palaeovegetational data to supplement those collected from other sites in the Lower Thames;

1.6.2 Determine the impact of sea level change on landscapes in the Dartford area during the Holocene.

1.6.3 Record the Quaternary stratigraphic sequence recovered in the boreholes according to standard geological criteria.

1.6.4 Correlate the stratigraphy of the geoarchaeological boreholes with the local and regional stratigraphic sequence.

1.6.5 Incorporate the new geoarchaeological stratigraphic data within existing deposit models thereby enabling the latter to be refined in terms of both precision and resolution.

1.6.6 Reconstruct the local and regional environment during the time of peat development (Neolithic to Late Roman periods according to previous ^{14}C dates), thereby determining both the role of humans in landscape change and the impact of changing environments on late prehistoric and early historic societies.

1.6.7 Publish a synthesis of the geoarchaeological works on the site in a suitable regional, national or international journal.

1.7 This report will directly assess objectives 1.6.1 to 1.6.6 outlined above.

2. METHODOLOGY

2.1 The WSI envisaged the drilling of three boreholes (ARCA BH6, BH7 and BH8) positioned in the northern part of the site (see Figure 1). Boreholes were located where:
a) The pile density of the new development would be high, and;
b) Where the Middle Organic Bed (MOB) is at its thickest.
While at the same time:
c) Positioning sample points within areas cleared by prior UxO surveys, and;
d) Avoiding areas set down to concrete. (Wilkinson 2013b, 2-3)

2.2 Drilling of the three new boreholes was carried out using Eijkelkamp drilling equipment. This comprises a 53mm diameter by 1000mm long core-sampler and 1000mm long extension rods driven by an Atlas Cobra petrol-powered drill. The equipment was operated by a crew of two. The core sampler was used to recover undisturbed cores of sediment to the base of the Holocene stratigraphy. Core samples were labelled and sealed on site and transported to ARCA's Winchester laboratory for further study.

2.3 Borehole locations were surveyed to Ordnance Survey National Grid Reference (NGR) and Ordnance Datum (OD) by Quest staff using a differential GPS device (shown in Figure 1).

2.4 In the laboratory the 53mm diameter plastic tubes containing the cores were sliced open using a bench mounted stone saw and a sharp blade was used to split the cores lengthways in two. One half of the core was used for sedimentary description while the other was wrapped in plastic film and placed in storage. The sediments revealed in the core half section used for stratigraphic description were carefully hand-cleaned, photographed and described using standard geological criteria (Tucker 1982, Jones *et al.* 1999, Munsell Color 2000). Following description the core half sections were wrapped in plastic film to minimise moisture loss and also placed in storage. The lithostratigraphy of the boreholes is reported in Section 3, full stratigraphic descriptions are given in Appendix 1.

2.5 Lithological and positional data from the three boreholes were then entered into the existing RockWorks database produced during the Phase 1 works (RockWare 2013, Wilkinson 2012). Following methods used during Phase 1, lithological units were assigned to one of the formal geological units mapped in the Lower Thames (Devoy 1979, Gibbard 1999). The updated

Rockworks database was then used to plot the composite cross sections of Figure 2 and Figure 3, and updated surface/thickness models of Figures 10 to 21. The latter were produced using a Kriging algorithm and are based on interpolations of strata recorded in varying numbers of boreholes depending on the particular surface/thickness to be modelled. It should be emphasised that the models need to be treated very cautiously, particularly in spatial locations where there are few data points (i.e. boreholes). Kriging algorithms are an effective way of interpolating data that are not uniformly distributed, but even so model uncertainty increases rapidly away from known points. The surface/thickness models are presented in Section 6, and are intended to supersede the previous models produced during the Phase 1 works (Wilkinson 2012).

2.6 Six sub-samples of 10mm thickness were extracted from organic strata in ARCA BH6 (four samples) and ARCA BH8 (two samples) for ^{14}C dating. The sub-samples were submitted to the Scottish Universities Environmental Research Centre (SUERC) for AMS ^{14}C measurement. Dates were calibrated using the IntCal13 calibration curve (Reimer *et al.* 2013) in the OxCal v.4 software package (Bronk Ramsey 2009). Linear age vs depth models for both boreholes were plotted using the Clam 2.2 software package (Blaauw 2010). The results are reported in Section 4.

2.7 Thirty-two sub-samples from borehole ARCA BH6 and thirty-eight from borehole ARCA BH8 were extracted for pollen analysis carried out in Quest's Reading laboratories. The pollen was extracted as follows: (1) sampling a standard volume of sediment (1ml); (2) adding two tablets of the exotic clubmoss *Lycopodium clavatum* to provide a measure of pollen concentration in each sample; (3) deflocculation of the sample in 1% Sodium pyrophosphate; (4) sieving of the sample to remove coarse mineral and organic fractions (>125μm); (5) acetolysis; (6) removal of finer minerogenic fraction using Sodium polytungstate (specific gravity of 2.0g/cm^3); (7) mounting of the sample in glycerol jelly. Each stage of the procedure was preceded and followed by thorough sample cleaning in filtered distilled water. Quality control is maintained by periodic checking of residues, and assembling sample batches from various depths to test for systematic laboratory effects.

2.8 An assessment of the pollen grains and spores was initially carried out on the samples from both boreholes. This assessment procedure consisted of scanning each slide along 4 transects (10% of the sample), noting the concentration, preservation, diversity and main taxa of the pollen grains and spores present. This procedure revealed that two thirds of the samples assessed from borehole ARCA BH6 contained a sufficient concentration of remains for analysis; this compared to only one of the samples from borehole ARCA BH8. On this basis, the samples from borehole ARCA BH6 underwent full analysis, whilst only the assessment results from borehole ARCA BH8 are displayed and interpreted (see Section 5.1).

2.9 Pollen grains and spores were identified using the University of Reading pollen type collection and the following sources of keys and photographs: Moore et al (1991); Reille (1992). The analysis procedure consisted of recording the pollen grains and spores present until a count of 300 total land pollen (TLP) was reached. The addition and counting of *Lycopodium* spores also permitted the calculation of total land pollen concentration (grains/cm^3). Microcharcoal with dimensions >20µm along at least one axis was counted, and concentrations calculated (fragments >20µm/cm^3). The results of the pollen assessment and analysis are reported in Section 5.1.

2.10 Fragments of waterlogged wood were extracted by eye from four levels in the main peat of ARCA BH6. Samples were examined following standard procedures for the microscopic analysis of waterlogged wood, as described in Hather (2000). The results are reported in Section 5.2.

2.11 Ten sub-samples from ARCA BH6 and fourteen from ARCA BH8 were extracted for diatom analysis. The diatom extraction involved the following procedures (Battarbee et al., 2001): (1) Treatment of the sub-sample (0.2g) with Hydrogen peroxide (30%) to remove organic material and Hydrochloric acid (50%) to remove remaining carbonates. (2) Centrifuging the sub-sample at 1200 for 5 minutes and washing with distilled water (4 washes). (3) Removal of clay from the sub-samples in the last wash by adding a few drops of Ammonia (1%). (4) Two slides prepared, each of a different concentration of the cleaned solution, were fixed in mounting medium of suitable refractive index for diatoms (Naphrax). Duplicate slides, each having two coverslips, were made from each sample and fixed in Naphrax for diatom microscopy. The coverslip with the most suitable concentration of the sample preparation was selected for diatom evaluation. A large area of this coverslip was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination using a Leica microscope. This procedure revealed that 80% of the samples from borehole ARCA BH6 were suitable for full analysis; this compared to only a third of the samples from borehole ARCA BH8. On this basis, the samples from borehole BH6 underwent full analysis, whilst only the assessment results from borehole BH8 are displayed, see Section 5.2.

2.12 Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Werff & Huls (1957-1974), Hartley et al. (1996), Krammer & Lange-Bertalot (1986-1991) and Witkowski et al. (2000). Diatom species' salinity preferences are discussed mainly using the classification data in Denys (1992), Vos & de Wolf (1988, 1993) and 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.

Diatom data were plotted graphically using the C2 software package (Juggins 2003). The results of the diatom assessment and analysis are reported in Section 5.3.

3. BOREHOLE STRATIGRAPHY

3.0.1 The borehole stratigraphy of the three boreholes drilled during the Phase 3 works is reported in detail in this section. The stratigraphy of the site as a whole is discussed in Section 6, and in the Phase 1 report (Wilkinson 2012).

3.0.2 Five major stratigraphic units (formal and informal members and beds) were encountered in the boreholes drilled during the Phase 3 works; these are reviewed below in chronological order.

3.0.3 The 'Lower fine-grained mineral bed' (LFGMB), 'Mineral organic bed' (MOB), and 'Upper fine-grained mineral bed' (UFGMB) units are informal divisions of the Tilbury Member (*sensu* Gibbard 1999) which were defined during the Phase 1 works (Wilkinson 2012).

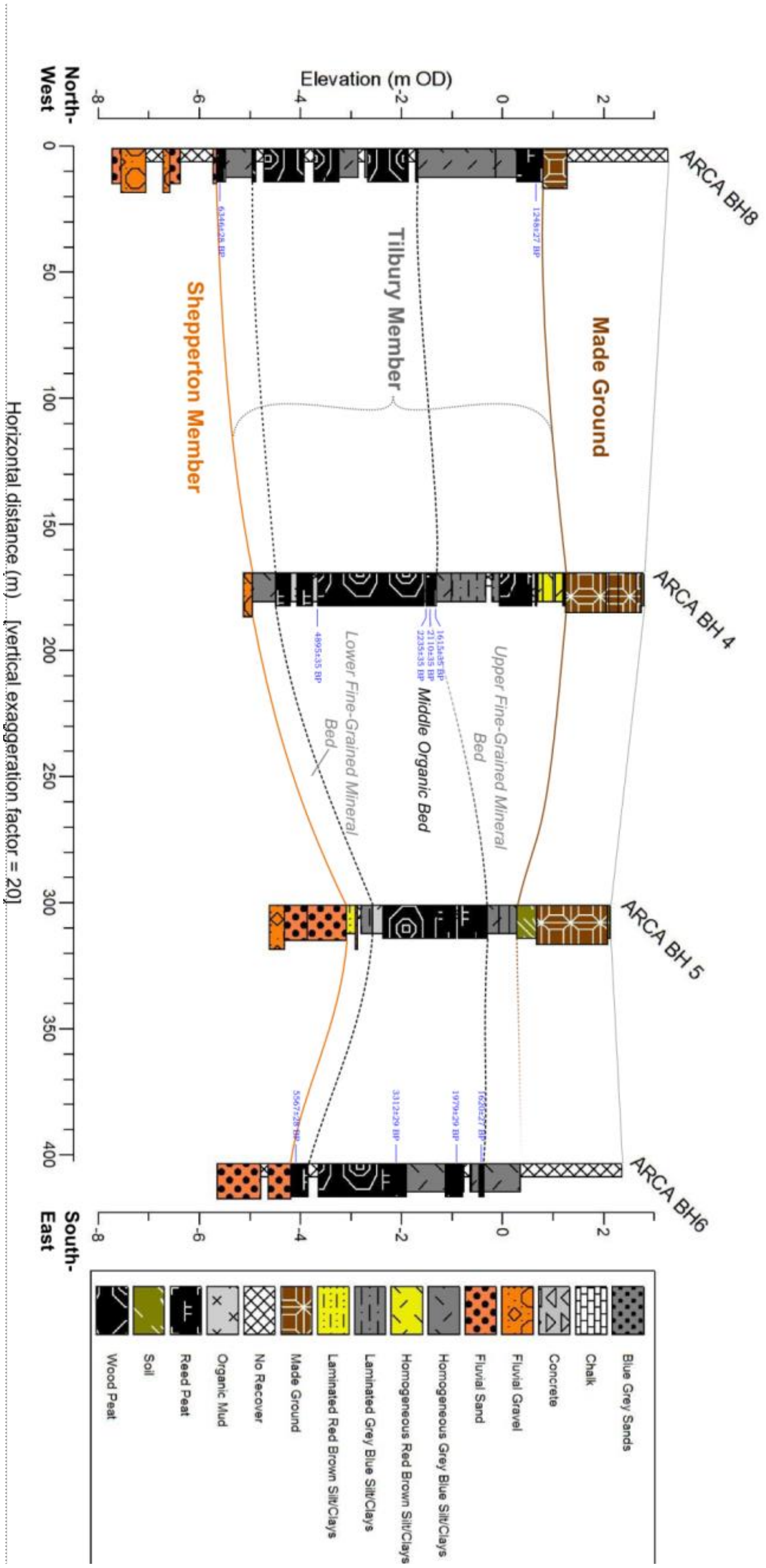

Figure 2: Northwest to southeast composite lithostratigraphic cross section.

3.1 Shepperton Member

3.1.1 Fluvial sands and gravels of the Shepperton Member were encountered at the base of all three boreholes drilled during the Phase 3 works. Although ARCA BH6, ARCA BH7 and ARCA BH8 did not penetrate to the base of the Shepperton Member, it is presumed to overlie chalk bedrock of the undifferentiated Seaford and Newhaven Formations (Upper Chalk).

3.1.2 The Shepperton Member outcrops at -4.19m OD in ARCA BH6, -7.97m OD in ARCA BH7, and -5.65m OD in ARCA BH8 and consists of olive grey sands and gravels of flint and chalk.

3.1.3 The Shepperton Member (*sensu* Gibbard 1999) formed in braided river environments during periglacial climates of the Late Pleistocene (Marine Isotope Stage [MIS] 2 - 24.0-11.5ky BP).

3.1.4 In all three boreholes, the Shepperton Member is overlain by the LFGMB.

3.2 Lower fine-grained mineral bed (LFGMB)

3.2.1 The LFGMB overlies the Shepperton Member and was encountered in all three Phase 3 boreholes. In these boreholes the LFGMB ranges between 0.54m (ARCA BH6) and 0.79m (ARCA BH7) in thickness, reflecting a general trend to increasing thickness towards the north. The LFGMB outcrops between -4.19m OD and -3.65m OD in ARCA BH6, -7.97m OD and -7.18m OD in ARCA BH7, and -5.65m OD and -4.95m OD in ARCA BH8.

3.2.2 During the Phase 1 works, the LFGMB was found to be comprised of three lithofacies: Lithofacies 1 (dark grey/black fine to medium sands laminated with organic muds); Lithofacies 2 (blue grey silt/clay, often laminated with organic mud and peat); and Lithofacies 3 (organic mud and well-humified reed peat) (Wilkinson 2012, 18-19). All three lithofacies were encountered in the Phase 3 boreholes.

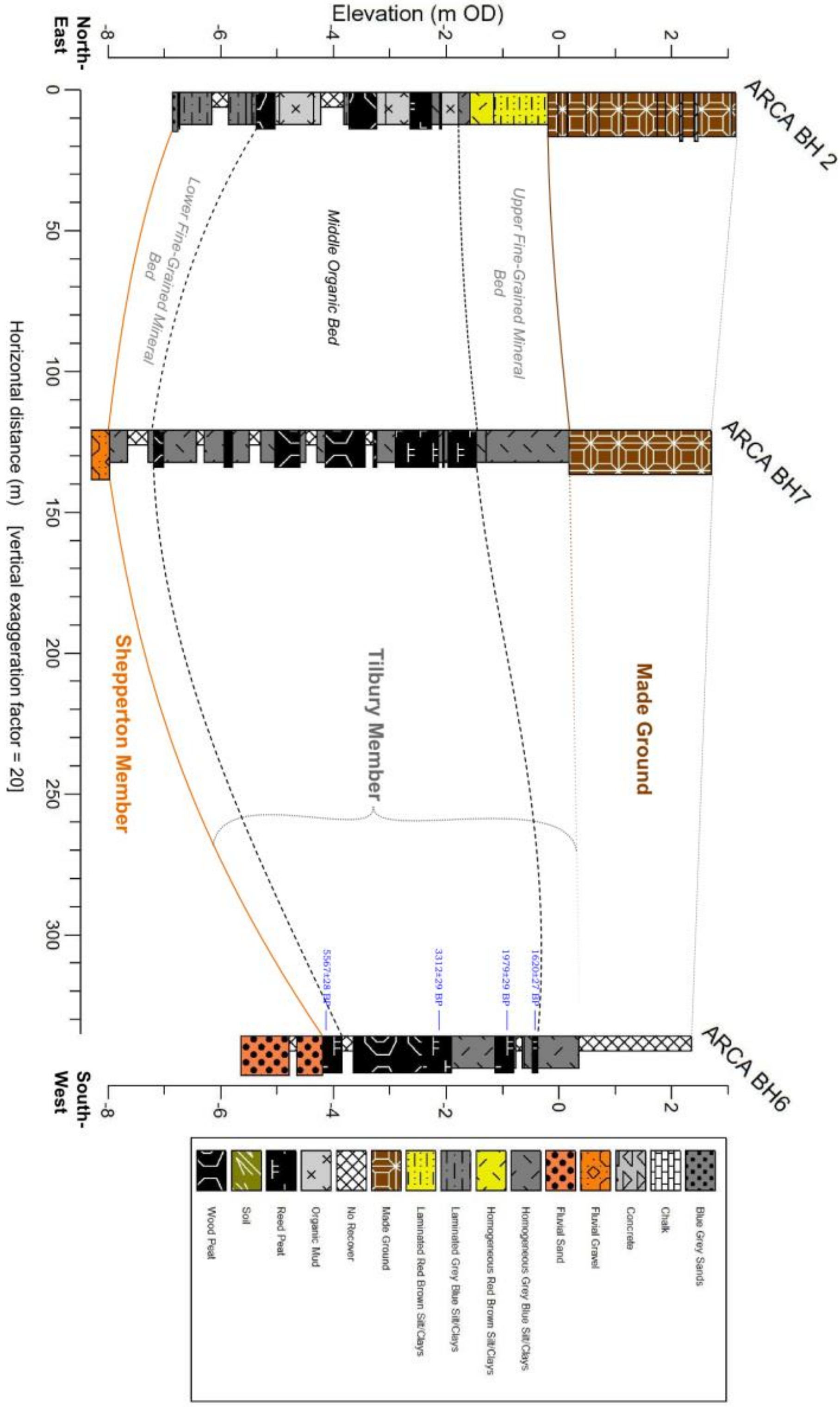

Figure 3: Northeast to southwest composite lithostratigraphic cross section.

3.2.3 Lithofacies 1 outcrops between -5.65m OD and -5.48m OD in ARCA BH8 and is composed of black organic mud with occasional fine sand and rare reed fragments. Lithofacies 1 is conformably overlain by Lithofacies 2 in ARCA BH8.

3.2.4 Lithofacies 2 outcrops between -5.48m OD and -4.95m OD in ARCA BH8 and between -7.97m OD and -7.18m OD in ARCA BH7 where it overlies the Shepperton Member. In both boreholes Lithofacies 2 is composed of homogenous grey silt/clays with rare to frequent granule to pebble-sized wood fragments.

3.2.5 Lithofacies 3 was encountered in ARCA BH6 outcropping between -4.19m OD and -3.85m OD and is composed of well-humified reed peat.

3.2.6 The LFGMB probably formed in the Early to Middle Holocene (Mesolithic period), initially in freshwater channels (Lithofacies 1), and later on intertidal mud flats (Lithofacies 2). Lithofacies 3 appears to have formed during a phase of estuary contraction leading to the development of a fen/carr; this event may correlate with Devoy's (1979) Tilbury II stage.

3.3 Middle organic bed (MOB)

3.3.1 The MOB is represented in the Phase 3 boreholes by wood peat, reed peat, and organic mud strata of between 2.85m and 5.75m thick and which conformably overlie the LFGMB.

3.3.2 The MOB is represented in the Phase 3 boreholes by a series of wood peat strata of varying humification overlain by well-humified reed peats, with occasional thin mineral silt/clay beds throughout. Wood peats outcropped between -3.65m OD and -2.42m OD in ARCA BH6, -7.18m OD and -3.23m OD in ARCA BH7, and -4.95m OD and -1.93m OD in ARCA BH8. Reed peats outcropped between -2.42m OD and -0.38m OD in ARCA BH6, -2.90m OD and -1.46m OD in ARCA BH7, and between -1.93m OD and -1.67m OD in ARCA BH8.

3.3.3 The MOB is likely to have formed initially on emergent salt marsh (reed peats) as relative sea level (RSL) rise slowed, and later in freshwater carr environments (wood peats) as marsh development at the site outstripped the falling trend in RSL rise. A later rise in RSL lead to the inundation of the freshwater carr giving rise to a return to saltmarsh conditions and the formation of reed peats overlying the wood peat strata. Occasional mineral-rich silt/clay facies within the MOB are likely to represent short-lived tidal inundation of the emergent marsh.

3.3.4 The MOB can be correlated with Devoy's (1979) Tilbury III peat, but might also include the Tilbury IV unit.

3.3.5 The MOB is conformably overlain by the Upper fine-grained mineral bed (UFGMB) in ARCA BH6, ARCA BH7, and ARCA BH8.

3.4 Upper fine-grained mineral bed (UFGMB)

3.4.1 The UFGMB outcrops between -0.38m OD and +0.35m OD in ARCA BH6, between -1.46m OD and +0.18m OD in ARCA BH7, and between -1.67m OD and +0.8m OD in ARCA BH8.

3.4.2 The UFGMB is mostly composed of grey homogenous silt/clays. The UFGMB is likely therefore to have formed in a similar mud flat environment to that discussed for Lithofacies 2 in the LFGMB, see Section 3.2.6. However, a unit of reed peat was encountered at the top of the UFGMB in ARCA BH8 which is likely to have formed during a further phase of estuary contraction.

3.4.3 The UFGMB is unconformably overlain by Made Ground.

3.5 Made Ground

3.5.1 'Made Ground' is a term used by the British Geological Survey to encompass deposits formed as a product of human action (BGS 2014).

3.5.2 Made Ground strata (up to 2.53m thick in ARCA BH7) were encountered at the top of all Phase 3 boreholes. Made Ground strata at the site are of highly variable lithology, but are typically formed of poorly sorted sands and silt/clays mixed with brick and concrete fragments, pieces of coal and other nineteenth and twentieth century detritus.

4. CHRONOLOGY

4.1 The results of AMS ^{14}C dating are presented in Table 1. A total of six subsamples were submitted to SUERC for AMS ^{24}C measurement: two subsamples from ARCA BH6, and four from ARCA BH8.

Borehole	Depth (m BGL)	Elevation (m OD)	Lab. No.	^{14}C age	Calibrated age (95% confidence)
ARCA BH6	2.78	-0.43	GU34073	1620±27 BP	1564-1473 cal BP (61.1%), 1467-1414 cal BP (33.9%)
ARCA BH6	3.30	-0.95	GU34072	1979±29 BP	1991-1877 cal BP (95%)
ARCA BH6	4.46	-2.11	GU34071	3312±29 BP	3609-3462 cal BP (95%)
ARCA BH6	6.45	-4.1	GU34070	5567±28 BP	6402-6303 cal BP (95%)
ARCA BH8	2.49	+0.79	GU32762	1248±27 BP	1271-1172 cal BP (76.1%), 1159-1117 cal BP (10.8%), 1114-1083 cal BP (8%)
ARCA BH8	8.83	-5.55	GU32763	6346±28 BP	7411-7397 cal BP (2%), 7366-7362 cal BP (0.5%), 7327-7239 cal BP (84.1%), 7220-7175 cal BP (8.3%)

Table 1: Results of AMS ^{14}C dating.
Calibration has been carried out using the IntCal13 curve (Reimer *et al.* 2013) and OxCal 4 software (Bronk Ramsay 2009).

4.2 The ^{14}C chronology demonstrates that the LFGMB formed during the Mesolithic period. Initial organic sedimentation in the area of ARCA BH8 occurred at 7400-7200 cal BP (GU32763, 6346±28 BP) after which intertidal mudflats developed due to RSL rise. Later still, emergent marsh began to develop in the area of ARCA BH6 at around 6400-6300 cal BP (GU34070, 5567±28 BP).

4.3 ^{14}C dates obtained from the middle and upper parts of the MOB range from the Early/Middle Bronze Age (GU34071, 3312±29 BP) to the Post Roman period (GU34073, 1620±27 BP). Very similar dates were obtained from ARCA BH4 which demonstrated that the MOB formed continuously from the Early Neolithic onwards (Wilkinson *et al.* 2012, 9). Mineral silt/clay strata within the upper part of the MOB in ARCA BH6, apparently formed during tidal inundations of the emergent marsh were deposited between 3610-3460 cal BP and 1990-1880 cal BP (i.e. between the Middle Bronze Age and the Roman period), and between 1990-1880 cal BP and 1560-1410 cal BP (between the Roman and Sub-Roman periods). Reed peat formed at the top of the UFGMB in ARCA BH8 appears to date to the Early Medieval period (GU32762, 6346±28 BP).

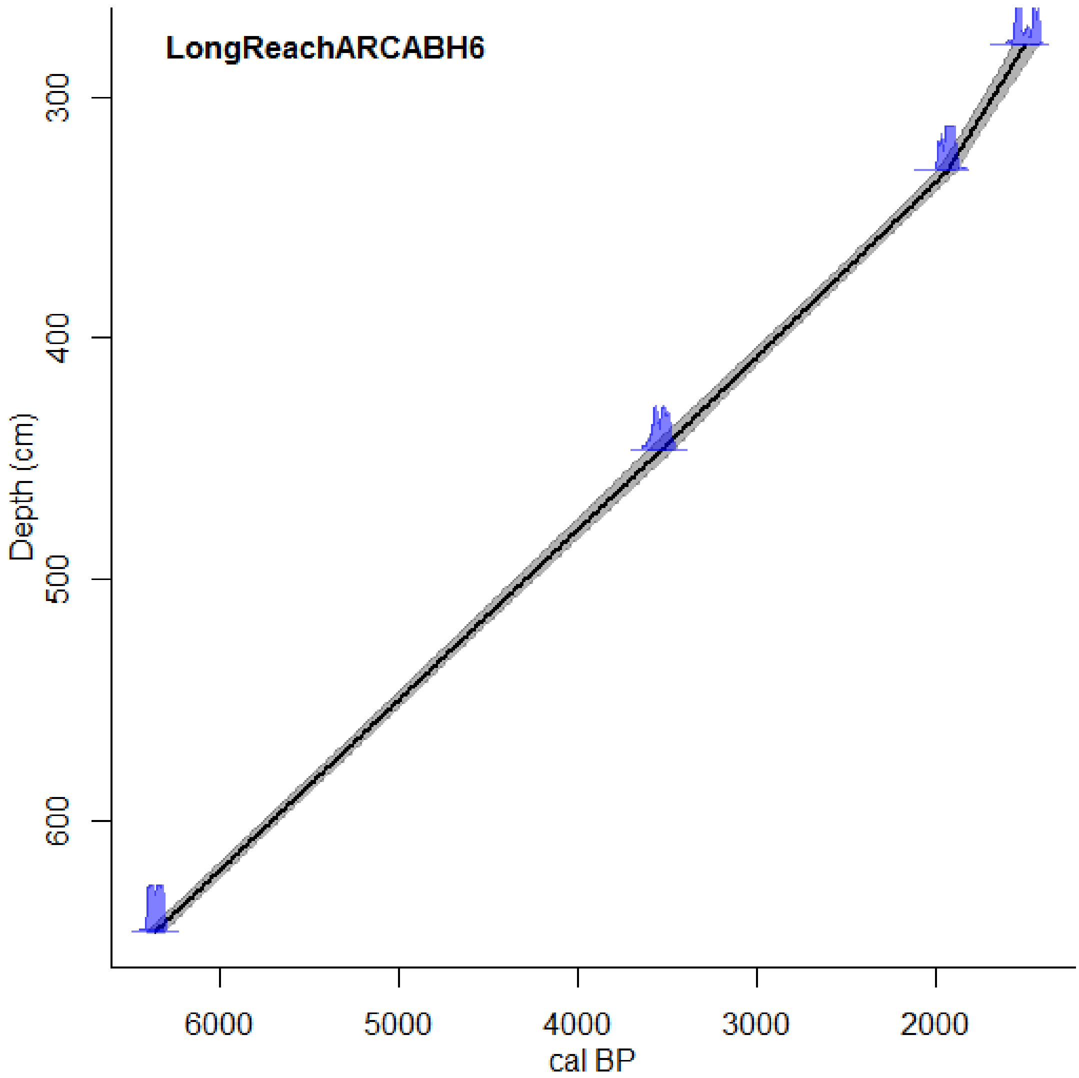

Figure 4: Age vs depth plot for ARCA BH6.

4.4 Age vs depth models for ARCA BH6 and ARCA BH8, using linear interpolation between the calibrated ^{14}C ages of the subsamples, were produced using Clam v.2.2 (Blaauw 2010). Figure 4 shows the age vs depth model for ARCA BH6. Modelled accumulation rates are relatively constant at *c.*14 yr cm^{-1} between 6400-6300 cal BP and 1990-1880 cal BP, but then increase to *c.*8 yr cm^{-1} between 1990-1880 cal BP and 1560-1410 cal BP. The linear age vs depth model for ARCA BH8 is shown in Figure 5; the modelled accumulation rate in this borehole is similar at *c.*10 yr cm^{-1}.

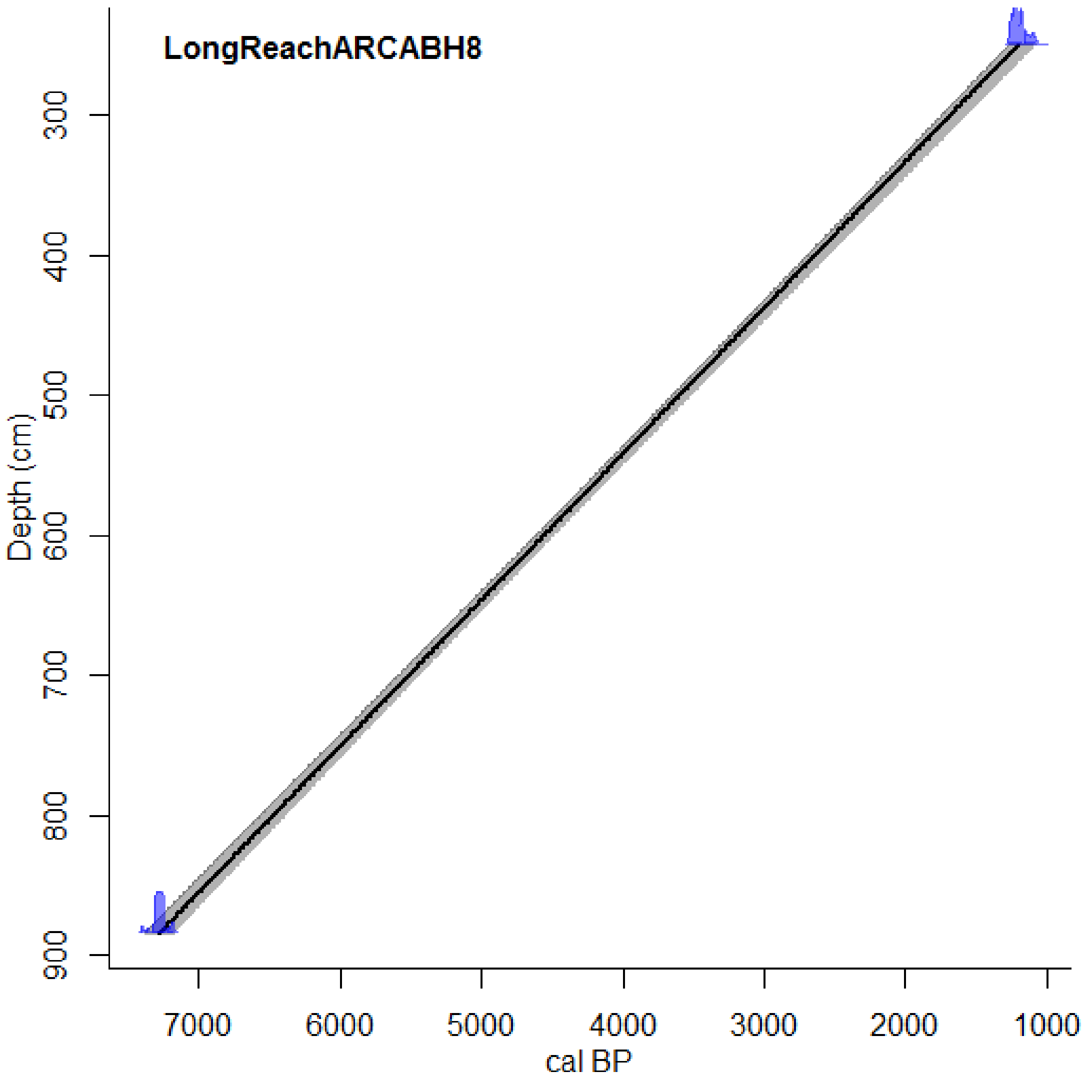

Figure 5: Age vs depth plot for ARCA BH6.

5. BIOSTRATIGRAPHY

5.1 Palynology

Rob Batchelor, Quest, University of Reading

5.1.1 Results ARCA BH6 analysis

5.1.1.1 Figure 6/Figure 7 have been divided into five local pollen assemblage zones (LPAZs LRBH6-1 to 5) based upon the results of the pollen analysis of 21 samples from ARCA BH6. As previously noted analysis was not carried out at eleven levels due to the poor concentration and preservation of remains; the principal taxa from four transects are however highlighted in the diagram. The assemblage zones are summarised below, prior to interpretation.

5.1.1.2 **LPAZ LRBH6-1 (-3.84 to -4.12m OD) Minimal pollen** This zone comprises 4 levels and is characterised by minimal concentrations of pollen. The dominance of tree and shrub taxa is dominated by sporadic occurrences of *Alnus*, *Quercus*, *Tilia*, *Ulmus*, *Corylus* type. Poaceae and *Filicales* were also recorded in single samples. Microcharcoal values were very high in three of the four samples.

5.1.1.3 **LPAZ LRBH6-2 (-3.20 to -3.84m OD) *Alnus – Quercus* - Cyperaceae** This zone is characterised by high values of tree (80%) and shrub (<10%) pollen. *Alnus* dominates (50%) with *Quercus* (20%), *Corylus* type (<10%), *Tilia*, *Ulmus*, *Fraxinus* (all <5%) and sporadic occurrences of *Betula*, *Ilex*, *Salix* and *Frangula alnus* (all <1%). Herbs are dominated by Cyperaceae and Poaceae with sporadic occurrences of Asteraceae, Artemisia, Lactuceae, *Rumex acetosa/acetosella*, *Ranunculus* type, *Chenopodium* type and *Mentha* type. Aquatic taxa are minimal including only a few grains of *Sparganium* type and *Typha latifolia*. Spores are dominated by *Filicales* with *Pteridium aquilinum* and *Polypodium vulgare*. Total pollen concentration is generally very high between -3.84 and -3.64m OD (460,000 grains/cm^3) before decreasing to ca. 40,000 grains/cm^3. Microcharcoal concentrations are relatively low-moderate through the zone, but increase markedly at -3.40m OD.

5.1.1.4 **LPAZ LRBH6-3 (-2.80 to -3.20m OD) Poaceae – *Quercus – Dryopteris* type** This zone is characterised by a decline in tree taxa, and increase in shrubs, herbs and spores. The decline in tree pollen is caused by a reduction in *Alnus* (from ca. 50% to <20%); the remaining tree taxa remain unchanged from LPAZ LRBH6-2, with the exception of a potential minor decline in *Ulmus* values. The decline in *Alnus* is in part reflected by an increase in *Corylus* type in the shrub assemblage. In the herbaceous assemblage, Cyperaceae declines (from >10% to <5%) whilst Poaceae increases markedly (to 35%). The diversity and quantity of herbs also increases to include *Rumex acetosa/acetosella*, *Ranunculus* type, Lactuceae, *Plantago* type, *P. lanceolata*, *Chenopodium* type, *Valeriana dioica* and *Mentha* type. Aquatic values remain very limited comprising sporadic occurrences of *Sparganium* type, *Typha latifolia* and *Menyanthes trifoliata*. Spore values increase markedly as a consequence of rising *Filicales* numbers, with some *Polypodium vulgare*. Total pollen concentration remains similar to that recorded at the top of LPAZ LRBH6-2 (<40,000grains/cm^3). Microcharcoal values are relatively high (17,000-75,000 fragments/cm^3).

5.1.1.5 **LPAZ LRBH6-4 (-2.12 to -2.80m OD) *Quercus* – *Corylus* type - Cyperaceae**

This zone is characterised by an increase in *Quercus* values (to 35%), more consistent values of *Tilia*, *Ulmus*, *Betula* and *Pinus* (<5%), and the occurrence of *Taxus* (<1%) in the arboreal assemblage. The shrub assemblage is characterised by an initial increase, then decline of *Corylus* type (to 25% then 15%). In the herbaceous assemblage, Poaceae declines (to 5%), whilst Cyperaceae increases (10-20%); other herbs include minor occurrences of *Chenopodium* type, *Ranunculus* type and *Rumex acetosa/acetosella*. Aquatic taxa comprise *Sparganium* type and *Typha latifolia* only. *Filicales* spores decline, whilst *Pteridium aquilinum* begins to increase at the top of the zone. Total pollen concentration remains similar to that recorded in LPAZ LRBH6-3. Microcharcoal concentrations are low to moderate.

5.1.1.6 **LPAZ LRBH6-5 (-0.44 to -2.12m OD) Cyperaceae - Poaceae**

The final zone is characterised by a marked decline in tree and shrub pollen (to 20% and <10% respectively), and increase of herbs and aquatics (to >60% and up to 5% respectively). *Quercus* (15%), *Alnus*, *Tilia*, *Ulmus*, *Corylus* type, *Fraxinus* and *Betula* all decline (to <5%), whilst minor increases of *Pinus* and *Fagus* are recorded. In the herbaceous assemblage, Cyperaceae and Poaceae increase to >40% and >20% respectively. The quantity and diversity of herbs also increases to include Poaceae >40um, Lactuceae, Asteraceae, *Plantago* sp., *Chenopodium* type, *Rumex acetosa/acetosella*, *R. obtusifolius*, *Ranunculus* type, *Polygonum aviculare* and *Galium* type. Aquatic taxa increase to include higher numbers of *Sparganium* type and *Typha latifolia*. *Pteridium aquilinum* dominates the spore assemblage with low quantities of *Polypodium vulgare* and *Filicales*. Total pollen concentration remains similar to that recorded in LPAZ LRBH6-3 and 4. Microcharcoal concentrations are low.

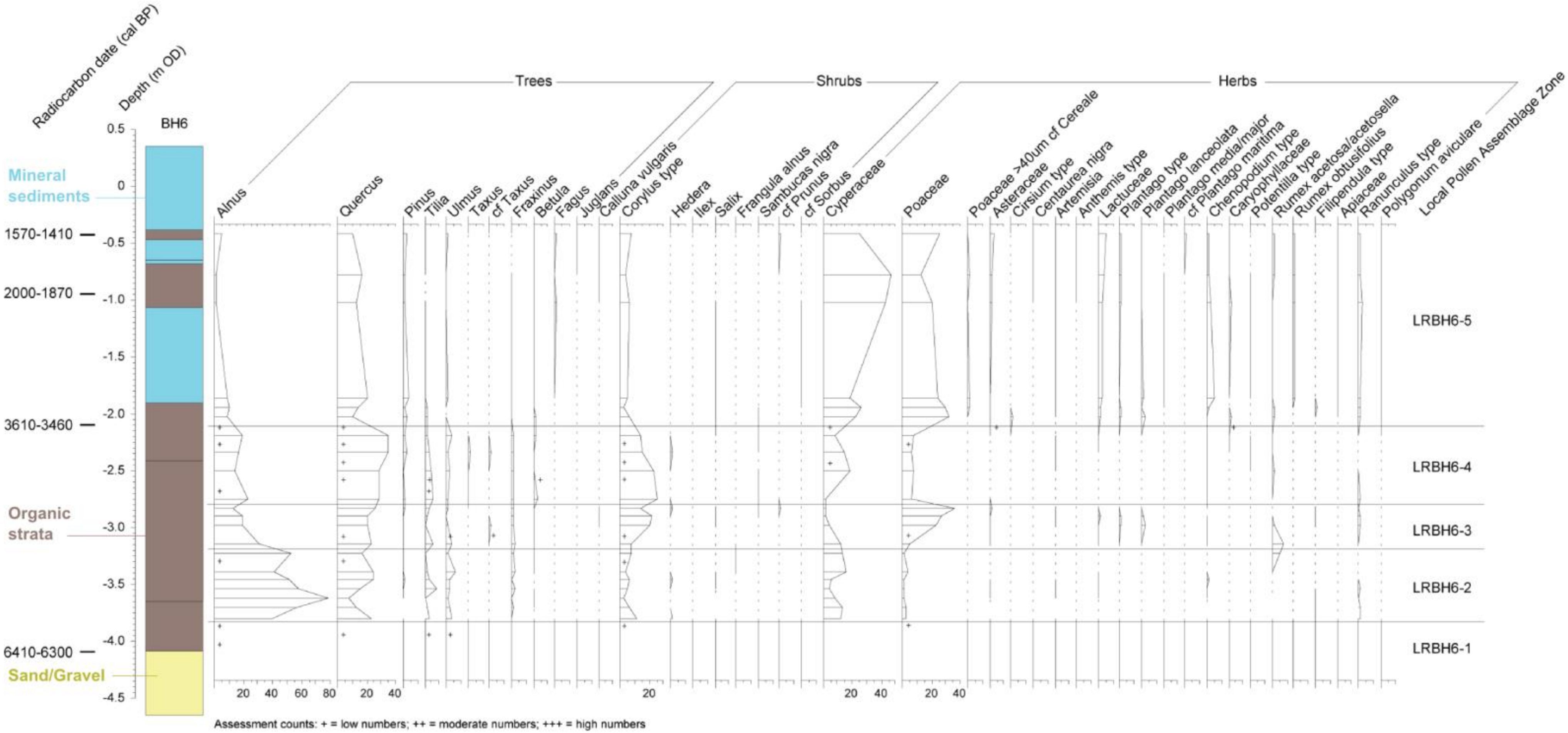

Figure 6: Percentage pollen-stratigraphic diagram, ARCA BH6, part 1. Diagram continued overleaf.

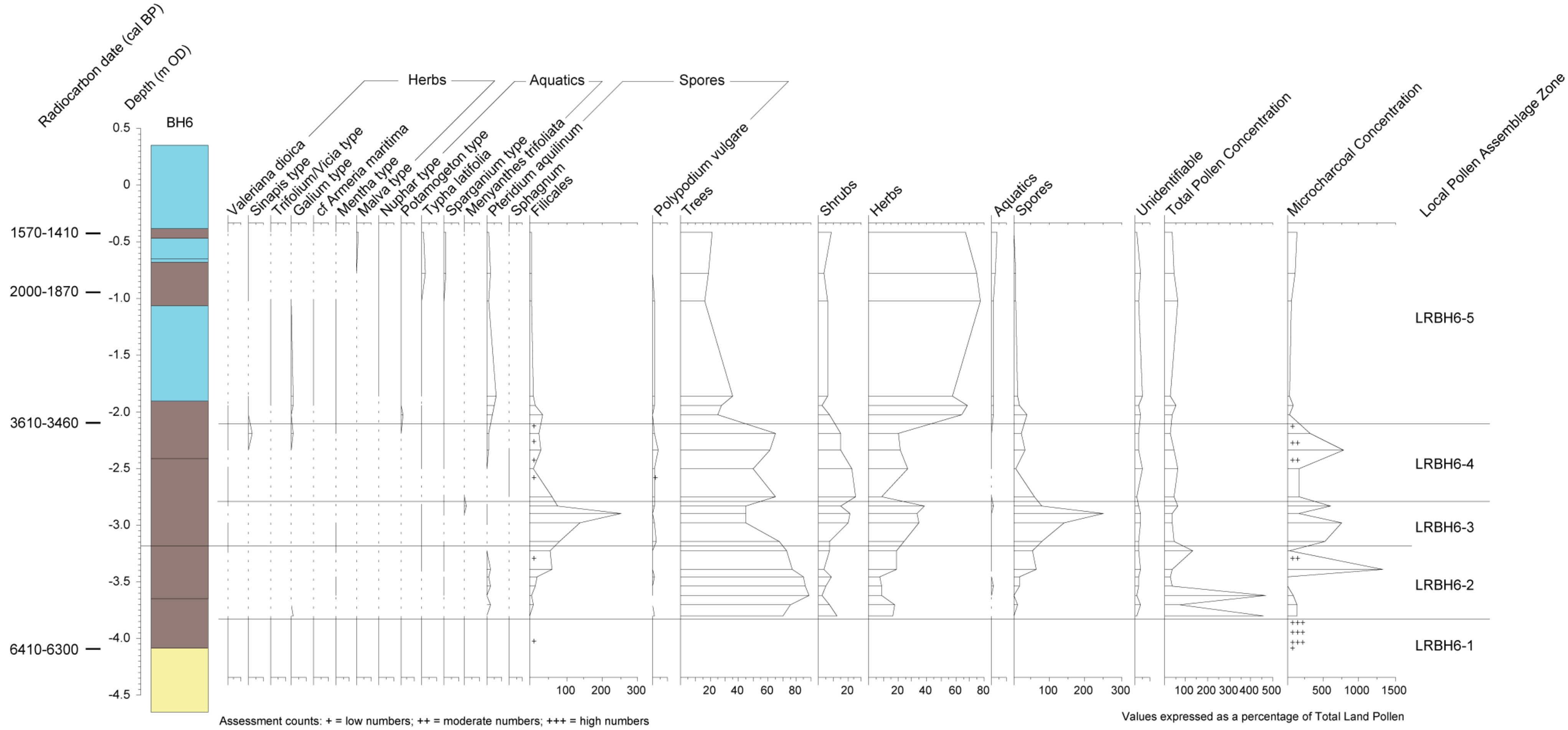

Figure 7: Percentage pollen-stratigraphic diagram, ARCA BH6, part 2. Continued from previous page.

5.1.2 Results ARCA BH8 assessment

5.1.2.1 The results of the ARCA BH8 pollen assessment are shown in Table 2. The results indicate a similar range of taxa encountered as in ARCA BH6, although little can be drawn from this information due to the limited counting possible. It is perhaps of note however, that very high values of microcharcoal are recorded in the LFGMB.

5.1.3 Interpretation ARCA BH6 analysis

5.1.3.1 At Long Reach, pollen analysis focused on parts of the sedimentary sequence most likely to represent semi-terrestrial or terrestrial environments on the wetland; i.e. the peats. Whilst this prevented a reconstruction of vegetation history through the complete sedimentary sequence (as carried out and advocated by Allen and Scaife, 2000), it did permit high-resolution analysis. Furthermore, and as outlined in detail by Allen and Scaife, there are a number of taphonomic issues that complicate the interpretation of palynological data from the mineral-rich sediments of low-energy fluvial and estuarine environments, including: (1) the long distance travel of pollen by fluvial or aeolian means (e.g. Moore *et al.*, 1991; Scaife and Burrin, 1992), and (2) the reworking and redeposition of pollen from older sediments (e.g. Cushing, 1967; Waller, 1993; Campbell, 1999). Concentration of the palaeoenvironmental analysis on the semi-terrestrial deposits reduces the impact of these particular taphonomic issues. However, another issue specific to pollen-analytical studies in coastal lowland wetlands is that of taxonomic precision and distinguishing the environment of origin. The identification of pollen grains (in particular herb taxa) is frequently limited by morphological similarities between grains of different species, and often only the genus can be established. In addition, the herbs found in one wetland habitat are often palynologically indistinguishable from other members of their genus/family that may have originated from different wetland or dryland environments (Waller, 1993, 1998; Waller *et al.*, 2005; see for example Wheeler, 1980a, 1980b). These issues are taken into account in the following interpretation.

	Depth (m OD)																		
	-3.71	-3.79	-3.87	-3.96	-4.04	-4.12	-4.19	-4.27	-4.36	-4.42	-4.44	-4.60	-4.75	-4.84	-5.36	-5.43	-5.51	-5.59	-5.67
Alnus	+	+	+	+		+	+		+	+	+	+	+	+	+				
Quercus	+	+	+	+	+	+	+	+		+	+	+	+	+	++	+			
Pinus				+			+		+			+				+			
Tilia	+		+	+		+		+	+	+	+			+	+	+			
Ulmus	+								+					+					
***Corylus* type**	+		+	+	+	+	+	+	+	+	+	+			+	+	+		
Cyperaceae	+				+	++	+	+			+		+	+	+	++	+		
Poaceae	+			+	+				+				+		+	+	+		
Poaceae >40um cf Cereale																			
***Plantago* type**								+											
Plantago lanceolata																			
***Chenopodium* type**																			
Rumex acetosa/acetosella				+			+				+								
Apiaceae																			
***Ranunculus* type**												+							
cf *Thalictrum* type															+				
***Sparganium* type**	+														+	+			
Pteridium aquilinum			+														+		
***Dryopteris* type**	+		+	++	+++	+++	+	+	+	+	++	++	+	+	+		+		
Polypodium vulgare							+		+	+		+							
Microcharcoal	++							+		+++			++	+++	+++	+++	+++	+++	+
Total Land Pollen	24	3	8	14	14	19	7	9	10	4	14	9	6	8	31	21	6	0	0
Suitable for analysis	**Y**	**N**	**N**	**Y**	**Y**	**N**	**N**	**N**	**N**	**N**	**Y**	**N**	**N**	**N**	**Y**	**Y**	**N**	**N**	**N**

Key:* + = *low numbers;* ++ = *moderate numbers;* +++ = *high numbers

Table 2: Results of pollen assessment ARCA BH8.

5.1.3.2 **LPAZ LRBH6-1 (-3.84 to -4.12m OD) Minimal pollen**

Peat accumulation commenced in ARCA BH6 from 6410-6300 cal BP (Late Mesolithic/Early Neolithic), and the initial stages are represented by LPAZ LRBH6-1. This zone is characterised by very limited pollen values which minimises the level of interpretation possible. Despite this, the presence of *Alnus* (alder), *Quercus* (oak), *Tilia* (lime), *Ulmus* (elm) and *Corylus* type (e.g. hazel) suggest that alder woodland occupied the peat surface whilst deciduous woodland grew on the dryland. The presence of Poaceae (grasses) and *Filicales* (ferns) suggests the growth of these taxa, most likely on the peat surface. High values of microcharcoal values suggest burning either on or nearby to the site. Whether this was of anthropogenic or natural origin is impossible to determine.

5.1.3.3 **LPAZ LRBH6-2 (-3.20 to -3.84m OD) *Alnus – Quercus* - Cyperaceae**

The result of the pollen-stratigraphic analysis indicate that during LPAZ LRBH6-2 (which is of probable Early Neolithic date), *Alnus* (alder) dominated the wetland environment with sporadic *Salix* (willow) and with a ground flora including Cyperaceae (sedges), Poaceae (grasses – e.g. *Phragmites australis* – common reed), *Ranunculus* type (buttercup / water crowsfoot), *Mentha* type (mint), *Sparganium* type (bur-reed), *Typha latifolia* (bulrush), *Filicales* (ferns – e.g. *Thelypteris palustris* – marsh fern) and *Polypodium vulgare* (polypody fern). These taxa indicate the development of alder fen carr growing on the peat surface and the presence of areas of still or standing dominantly freshwater. *Quercus* (oak), *Ulmus* (elm), *Betula* (birch), *Fraxinus* (ash) and *Corylus* type (e.g. hazel) may also have accompanied alder and willow on the peat surface. These taxa more commonly occur, however, on dryland where they would have formed a mosaic of mixed deciduous woodland with *Tilia* (lime). The understorey would have comprised hazel shrubs together with grasses and a range of herbs more commonly found in rough grassland. The gradual decline of alder from midway through the zone does, however, suggest that the composition and structure of the alder carr woodland did undergo change. This decline appears to correlate with an increase microcharcoal concentration and of ferns. Combined, this is strongly suggestive of an episode of burning on or nearby to the peat surface, potentially resulting in opening up of the floodplain woodland. As outlined above, whether this episode was of anthropogenic or natural origin is not possible to determine. However, since there is no decline in dryland pollen types (e.g. *Quercus* and *Tilia*), or increase of light-loving hazel, it appears that the episode of burning may not have expanded beyond the nearby vicinity. The presence of *Chenopodium* type (goosefoot family) is also of note here, since genera of the Chenopodiaceae family can occur in two main locations: (1) waste, dry ground and cultivated land (e.g. *Chenopodium album* – fat hen), and (2) salt marshes (e.g. *Suaeda maritima* – annual sea-blite). Although the former may be growing nearby as a consequence of the burning episode, it is not a plant associated with peat surfaces. Thus the presence of *Chenopodium* type pollen is considered more likely to represent occasional fluvial inundation of the site and the influence of estuarine conditions.

5.1.3.4 **LPAZ LRBH6-3 (-2.80 to -3.20m OD) Poaceae – *Quercus* – *Dryopteris* type**

The results indicate that during LPAZ LRBH6-3, the wetland environment underwent a change in vegetation. A decline in *Alnus* and Cyperaceae values suggests a reduction in alder carr woodland, probably to drier areas of the floodplain such as the floodplain/dryland interface. This was replaced by tall herb and fern swamp as indicated by increased grasses/reeds, ferns (e.g. *Thelypteris palustris*) buttercup/waters crowfoot and sorrel (*Rumex acetosa*/*acetosella*), mint, marsh valerian (*Valeriana dioica*), thistle (*Cirsium* type), bulrush, bur-reed and bogbean (*Menyanthes trifoliata*). The minimal presence of *Chenopodium* type represents a continued potential indicator of estuarine conditions during this period. Poorly preserved *Plantago* type taxa may also be representative of the growth of *Plantago maritima* (sea plantain). Mixed deciduous woodland dominated by oak and lime continued to occupy the dryland during LPAZ LRBH6-3. A potential decline in *Ulmus* is recorded towards the bottom and top of the zone, which might be representative of the well-documented Early Neolithic elm decline. This phenomenon is frequently recorded in pollen diagrams across the Lower Thames Valley (e.g. Batchelor *et al.*, in press) and indeed across the British Isles generally (Parker *et al.*, 2002) between approximately 6300 and 5300 cal BP. It is of note that this period also contains evidence for increasing hazel, suggesting that the woodland became increasingly open in character, perhaps composed of glades, permitting light-loving taxa to grow. Since relatively high values of microcharcoal are also recorded, it is possible that these glades were produced by episodes of burning.

5.1.3.5 **LPAZ LRBH6-4 (-2.12 to -2.80m OD) *Quercus* – *Corylus* type - Cyperaceae**

The results of the pollen-stratigraphic analysis indicate further changes in vegetation on the peat surface during LPAZ LRBH6-4. This time, a decrease of tall herb and fern vegetation is indicated, to be replaced by sedge fen. Other herbs such as thistles, dandelions, buttercups/water crowsfoot, bulrush, bur-reed and marsh valerian also continued to occupy the peat surface. Mixed deciduous woodland dominated by oak and lime continued to occupy the dryland with elm, ash and birch. Increasing hazel values towards the base of the zone suggest that the woodland became increasingly open in character, perhaps supporting a greater number of glades. From midway through the zone however, this trend reverses. This correlates with an increase of oak and apparent colonisation of yew (*Taxus*), suggestive of vegetation succession. Towards the very top of the zone, higher values of microcharcoal are recorded together with an increase in *Pteridium aquilinum*, indicative of further episodes of anthropogenic or natural burning.

5.1.3.6 **LPAZ LRBH6-5 (-0.44 to -2.12m OD) Cyperaceae - Poaceae**

The final zone commences towards the top of the wood peat strata within the MOB, and continues through the two thinner reed peats towards the top of the MOB. The transition to LPAZ LRBH6-4 to LRBH6-5 is characterised by a further decline in alder woodland on the peat surface and of mixed deciduous woodland on the dryland. On the floodplain, the decline of alder woodland is reflected by a large increase in grasses, sedges, *Chenopodium* type and various herbs and aquatics. This assemblage is suggestive of a shift towards sedge fen, reed swamp and salt-marsh communities and a strong estuarine influence, most likely consequent of an increase in RSL rise. It is of note that *Pinus* and *Pteridium aquilinum* also increase during this period. Both taxa are frequently over-represented in alluvial environments as a consequence of their morphology which allow them to float long distances (e.g. Campbell, 1999). On the dryland, the decline of oak, lime and hazel is suggestive of a large reduction in mixed deciduous woodland. The increase of a large array of herbaceous taxa including potential cereal pollen suggests that this decline was a consequence of woodland clearance for settlement and agricultural purposes which took place from the Bronze Age onwards. However, it is of note that the decline does not correlate with an increase of microcharcoal as might be expected. Whether the decline of wetland and dryland woodland is linked is uncertain, but does seem to be a common feature of woodland within pollen-stratigraphic diagrams from the Lower Thames Valley (see Section 7).

5.2 Waterlogged wood

Phil Austin

5.2.1 Waterlogged wood was hand-picked from four levels in ARCA BH6. Of the 16 fragments examined two were identified as *Alnus glutinosa* (alder), a taxon associated with wetland environments, one was an unidentified hardwood, and the remainder were fragments of bark from an unknown source. Ring curvature suggests that the alder wood probably derived from a small branch. It was not possible to determine the nature and quantity of seasonal rings because of poor preservation and the small dimensions of the fragments. The bark fragments were relatively large and thick indicating perhaps that they derived from mature stem wood.

5.3 Diatoms

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5.3.1 ARCA BH6 analysis

5.3.1.1 The quality of diatom preservation in the borehole ARCA BH6 sequence is generally good, with 80% of the samples containing sufficient concentrations for analysis (Figure 8/Figure 9). This compares with borehole ARCA BH8 in which the concentration and preservation was almost always poor or very poor (see Section 5.2.2 and Table 3). The poor preservation of diatom assemblages may be the result of a number of factors; for example silica dissolution as a result of unfavourable water quality or because of the exposure of diatom valves to physical damage (Flower 1993, Ryves *et al.* 2001). The following account provides the results of the borehole ARCA BH6 sequence only. Interpretation and discussion of the sea level history of the site is given in Section 7.1.

5.3.1.2 No diatoms were preserved in samples taken from the base of the sequence towards the interface between the Shepperton Member and overlying organic strata within the LFGMB (-4.11m OD and -4.04m OD).

5.3.1.3 At the top of the main peat stratum within the MOB (-1.96m OD) the diatom assemblage is dominated by oligohalobous indifferent taxa; this halobian group, which has optimal growth in freshwater, represents 53% of the total diatoms. The most common diatoms are opportunistic species (Denys 1988) with broad salinity tolerance and include *Fragilaria pinnata* (45%) and *Fragilaria brevistriata*. However, the influence of tidal water is reflected by the common occurrence of taxa from both the mesohalobous (20%) and polyhalobous (13%) halobian groups. The former group includes the planktonic estuarine species *Cyclotella striata* (15%) and the latter a range of taxa including *Cymatosira belgica, Paralia sulcata, Rhaphoneis* spp. and *Thalassionema nitzschiodes*.

5.3.1.4 Within the next sample from the overlying silt/clay layer within the MOB (-1.88m OD), the percentage of oligohalobous indifferent taxa declines to 13% whilst halophilous diatoms increase to 24%, mesohalobous taxa to 22% and polyhalobous taxa increase to 27% of the total diatoms. Again the most common oligohalobous indifferent diatoms include those with broad environmental tolerances such as *Fragilaria pinnata* and *Fragilaria brevistriata*. Other freshwater taxa from shallow water habitats include *Achnanthes lanceolata, Amphora libyca* and *Nitzschia amphibia*. The halophilous diatoms include aerophilous types such as *Navicula cincta* (4%), and *Navicula mutica*, which represents 20% of the total diatoms. These desiccation tolerant diatoms are able to inhabit semi-terrestrial environments. Again the influence of tidal water is shown by the presence of mesohalobous diatoms particularly the planktonic diatom *Cyclotella striata* and benthic species *Nitzschia navicularis*. The increased abundance of polyhalobous taxa includes *Cymatosira belgica, Paralia sulcata, Rhaphoneis* spp. and *Thalassionema nitzschiodes*. Benthic marine-brackish diatoms derived from shallow water include *Diploneis smithii*.

5.3.1.5 Towards the top of the silt/clay layer (at -1.11m OD), below the next reed peat stratum within the MOB, polyhalobous diatoms comprise 20% of the assemblage, mesohalobous diatoms 18%, halophilous taxa 11% and oligohalobous indifferent diatoms 36% of the total. The most common oligohalobous indifferent diatoms are again diatoms with broad environmental tolerances such as *Fragilaria pinnata, Fragilaria construens* var. *venter* and *Fragilaria brevistriata*. However, other freshwater taxa include *Achnanthes lanceolata, Achnanthes clevei* and *Amphora pediculus*. These diatoms represent shallow, freshwater environments. The most common halophilous species are the aerophilous diatoms *Navicula cincta* and *Navicula mutica*. Mesohalobous diatoms include a low percentage of the planktonic diatom *Cyclotella striata*, with benthic taxa such as *Nitzschia navicularis, Rhopalodia musculus, Synedra pulchella* and *Achnanthes brevipes*. The most common polyhalobous diatoms at 3.46m BGL are *Cymatosira belgica, Paralia sulcata, Campylosira cymbelliformis, Rhaphoneis minutissima* and *Thalassionema nitzschiodes*.

5.3.1.6 At -1.03m OD, towards the base of a further reed peat horizon in the upper part of the MOB, polyhalobous diatoms are absent from the assemblage, oligohalobous indifferent diatoms increase to 73% of the total, halophilous diatoms decline to less than 1% and mesohalobous taxa comprise 12% of the total diatoms. Again the dominant components of the oligohalobous indifferent diatoms are opportunistic *Fragilaria* spp. with broad environmental tolerances. The mesohalobous diatoms include *Synedra pulchella, Synedra tabulata, Rhopalodia musculus, Nitzschia hungrica* and *Cyclotella striata*. With the exception of *Cyclotella striata* these are species that live in shallow water.

5.3.1.7 In the four uppermost samples of the sequence (-0.71m, -0.63m, -0.51m and -0.35m OD), all of which are associated with the UFGMB, the percentages of polyhalobous diatoms increase from 2% to 9% to 13% and to a maximum of 23% in the uppermost sample. Mesohalobous taxa increase from 6% and 4% in the bottom two samples at 3.06m and 2.98m, to 40% and 42% at 2.86m and 2.70m. Halophilous diatoms increase from 1% to 6% at the top of the sequence. Oligohalobous indifferent diatoms decrease from a maximum of 87% at 3.06m to 77% at 2.98m, 13% at 2.86m and 12% at 2.70m. The most marked differences in the composition of the diatom halobian groups appears between the high percentages (87-77%) of freshwater taxa in the lower two samples with low percentages of mesohalobous diatoms (*ca.* 5%) in these samples; and the switch to high percentages of mesohalobous diatoms in the top two samples (*ca.* 40%) with lower abundance of oligohalobous indifferent taxa in these top two samples (12-13%).

5.3.1.8 Again in the four uppermost samples of the sequence, the most common taxa of the oligohalobous indifferent group are opportunistic *Fragilaria* spp. that have broad environmental tolerances. These *Fragilaria* taxa include *Fragilaria pinnata, Fragilaria construens* var. *venter, Fragilaria* sp. 1 and *Fragilaria brevistriata.* More common in the top two samples, the halophilous to oligohalobous indifferent, halophilous, and mesohalobous to halophilous groups include a range of shallow water, non-planktonic diatoms such as *Rhoicosphaenia curvata,* *Epithemia turgida, Navicula mutica, Navicula cincta, Nitzschia levidensis*; along with some halophilous planktonic diatoms such as *Actinocyclus normanii* and *Cyclotella meneghiniana*. The greater abundance of halophilous diatoms, particularly the non-planktonic species, in the top two samples provides supporting evidence for increasing salinities. The main mesohalobous group increases from low percentages in the bottom two samples to dominate the top two samples and the primary diatoms of this group are the benthic, mud surface species *Nitzschia navicularis*, and the planktonic estuarine diatom *Cyclotella striata*. A range of marine and marine brackish taxa are present and increase in the top four samples of the borehole. These polyhalobous and polyhalobous to mesohalobous diatoms include *Cymatosira belgica, Paralia sulcata, Podosira stelligera, Rhaphoneis* spp., *Actinoptychus undulatus* and *Diploneis smithii*

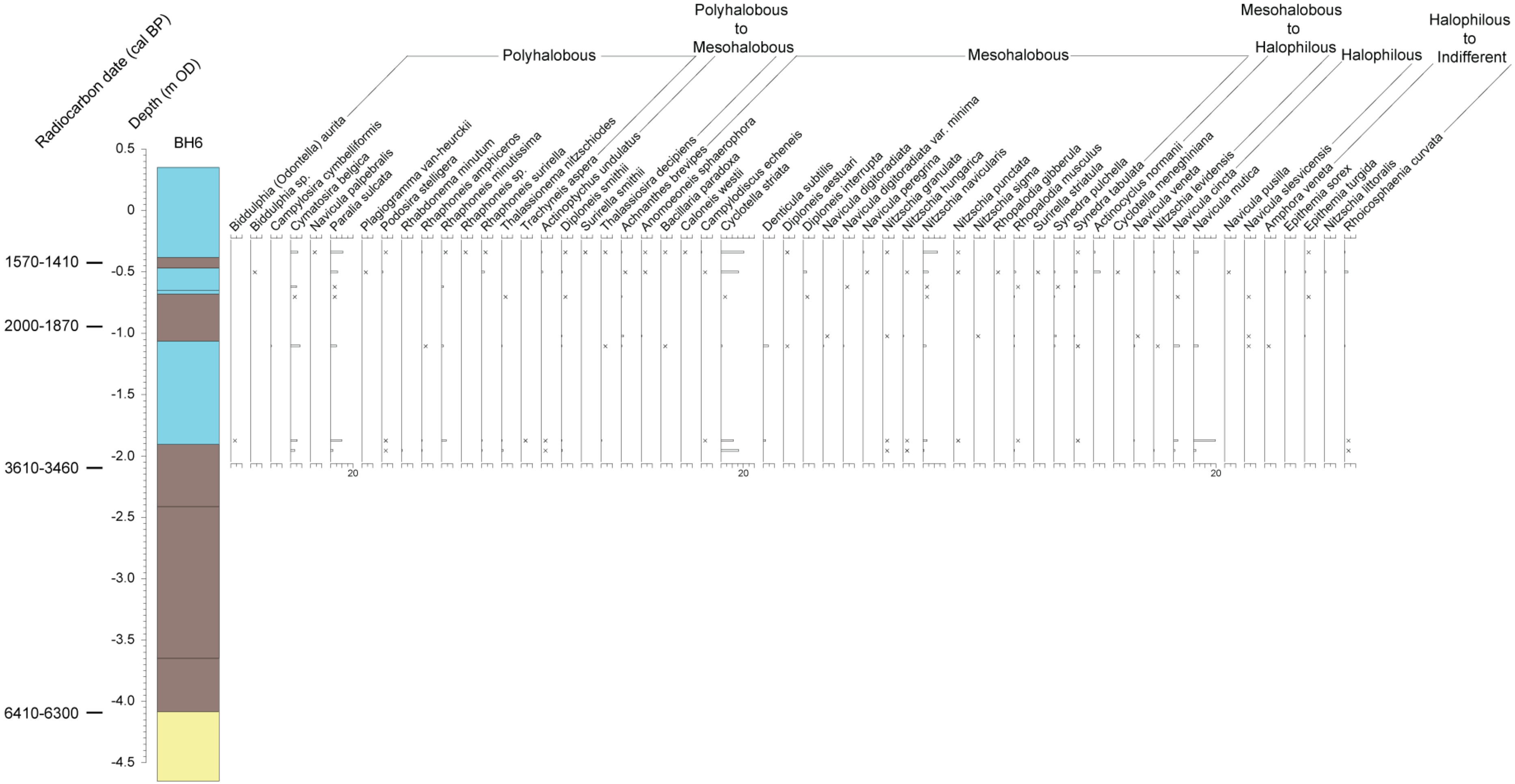

Figure 8: Percentage diatom diagram, ARCA BH6, part 1. Diagram continued overleaf. See Figure 6 for lithostratigraphy key.

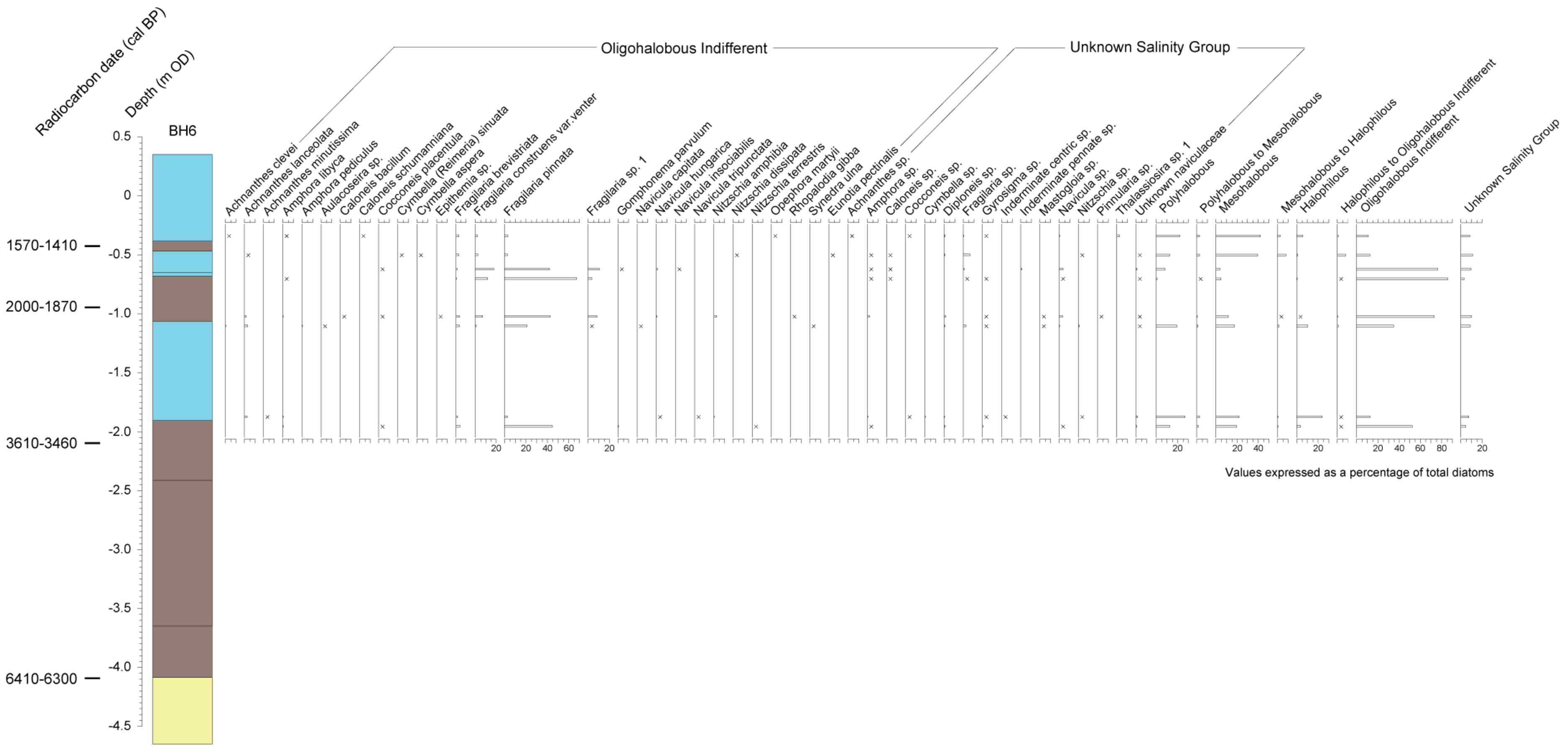

Figure 9: Percentage diatom diagram, ARCA BH6, part 2. Diagram continued from previous page.

5.3.2 ARCA BH8 assessment

5.3.2.1 The results of the diatom assessment are displayed in Table 3. Only two samples contained a suitable number of diatoms for analysis.

Depth (m OD)	**Concentration**	**Preservation**	**Diversity**	**Suitable for analysis**
+0.32	2	3-4	Moderate	Yes
+0.24	1	1	Fragments only	No
-1.66	5	3-4	High	Yes
-1.74	1	1	Fragments only	No
-2.62	2	2	Low	No
-2.70	2	2	Low	No
-3.16	0	0	-	No
-3.32	0	0	-	No
-4.76	1-2	1-2	Fragments only	No
-4.84	0	0	-	No
-5.36	2	1-2	Fragments only	No
-5.44	1-2	1-2	Fragments only	No
-5.60	0	0	-	No
-5.68	0	0	-	No

Table 3: Diatom assessment ARCA BH8.

6. DEPOSIT MODELS

6.1 Deposit models were generated using the Rockworks 14 (Rockware 2013) and the stratigraphic thickness and surface models presented in Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, and Figure 21 were produced. These models were based on those generated during Phase 1 of the project (Wilkinson 2012), and were updated with data from boreholes drilled during the 2013 watching brief (Wilkinson 2013a), and the Phase 3 works presented here.

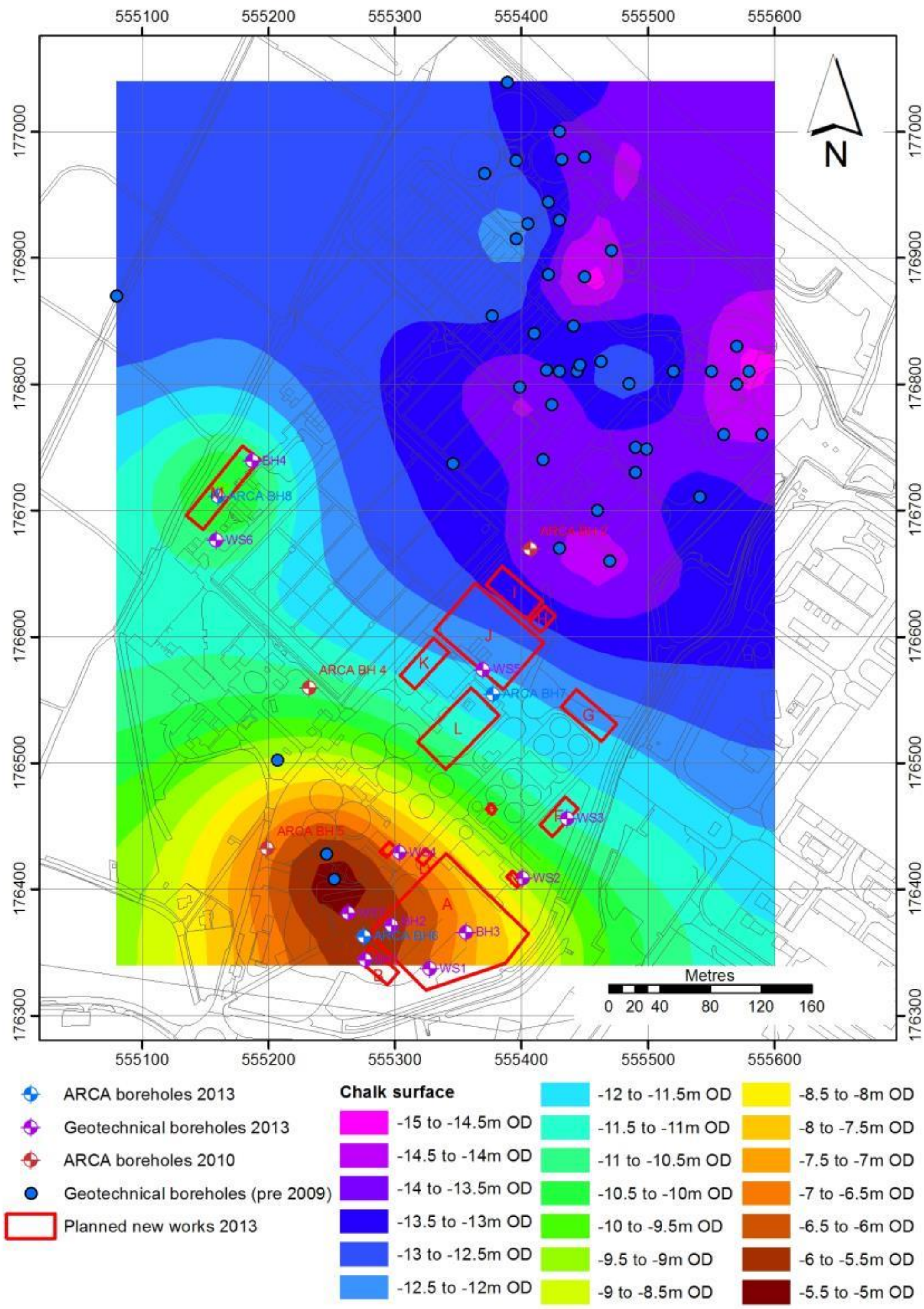

Figure 10: Modelled surface of the undifferentiated Newhaven and Seaford Formations (Upper Chalk).

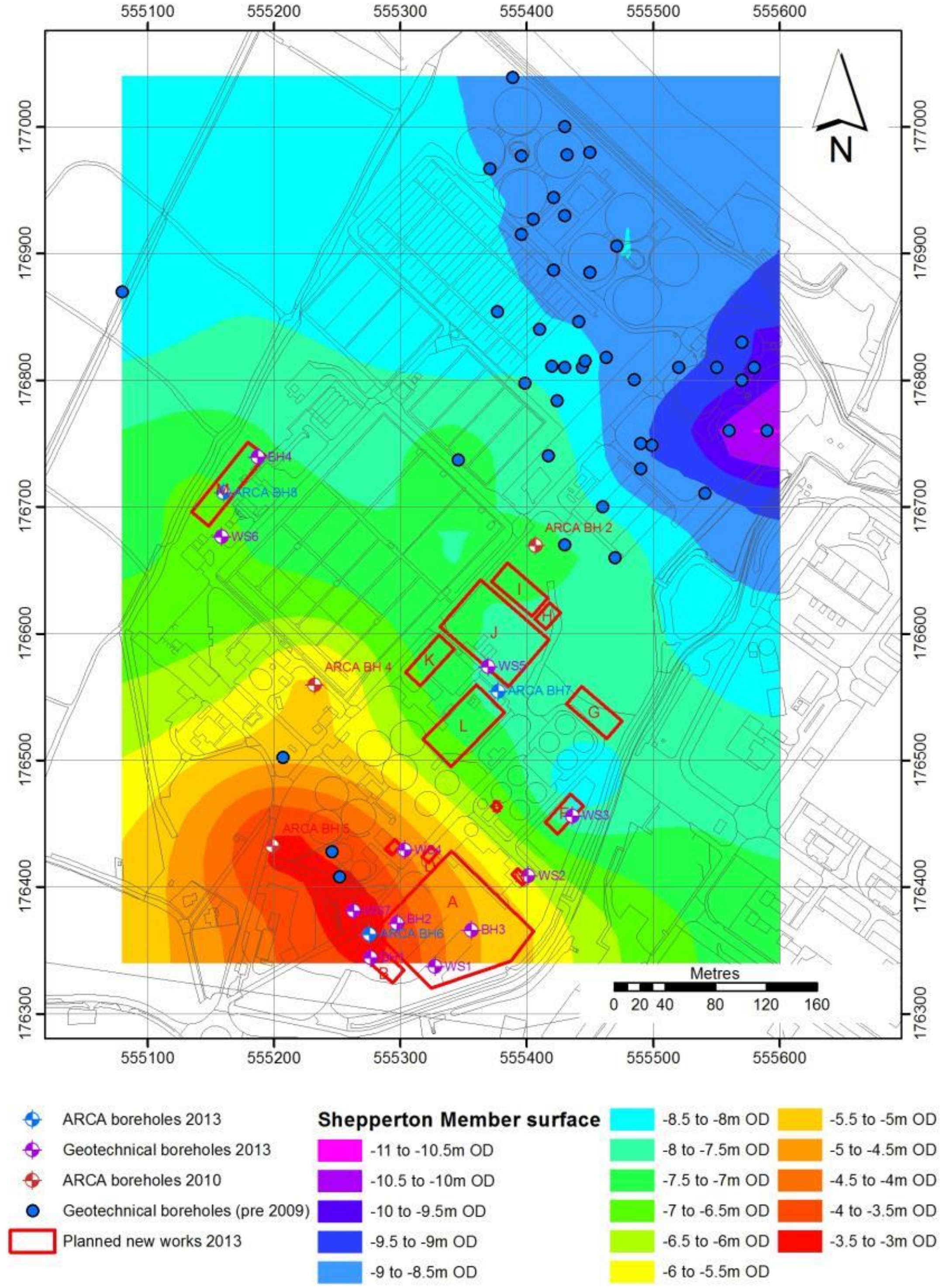

Figure 11: Modelled surface of the Shepperton Member.

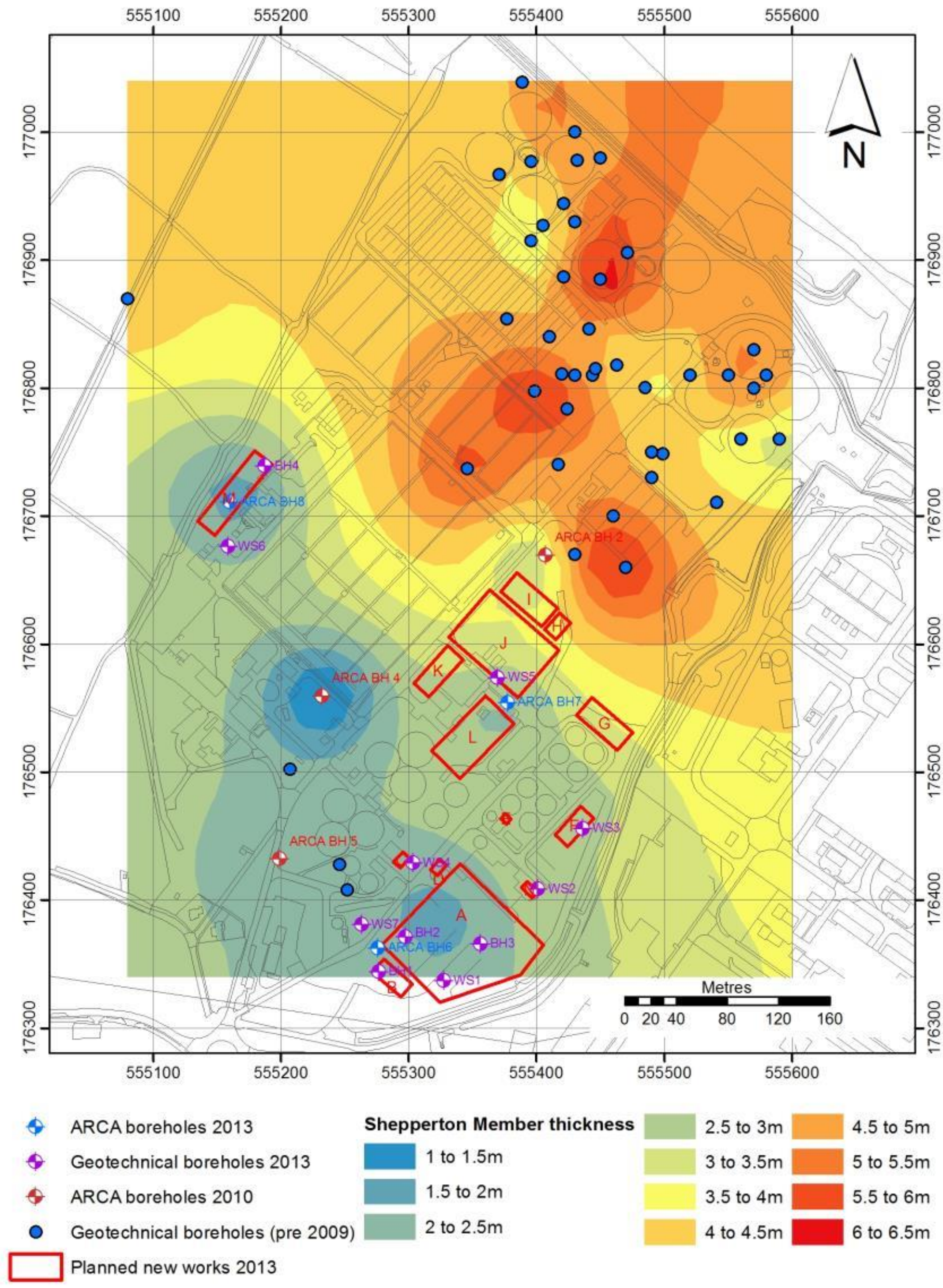

Figure 12: Modelled thickness of the Shepperton Member.

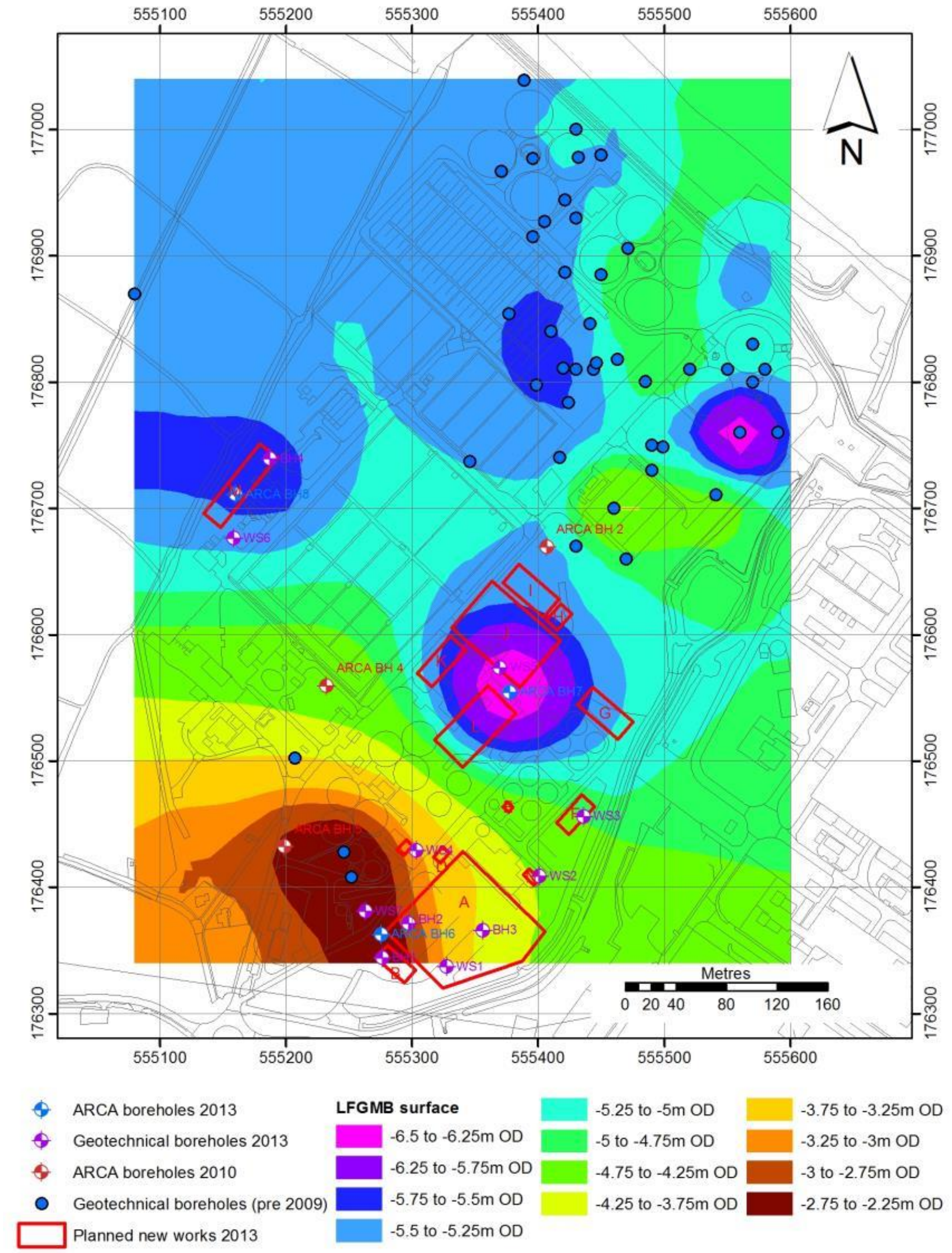

Figure 13: Modelled surface of the LFGMB.

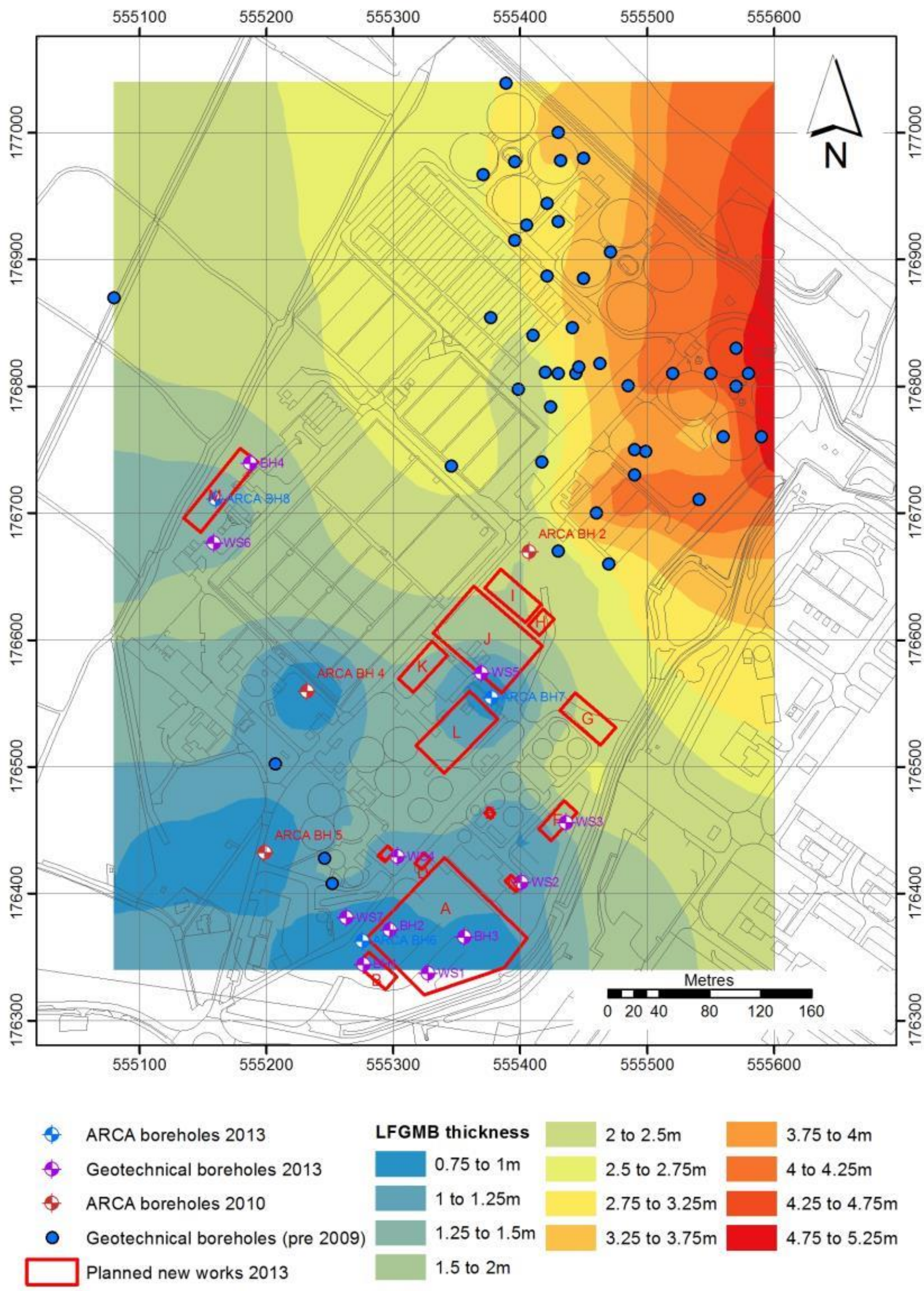

Figure 14: Modelled thickness of the LFGMB.

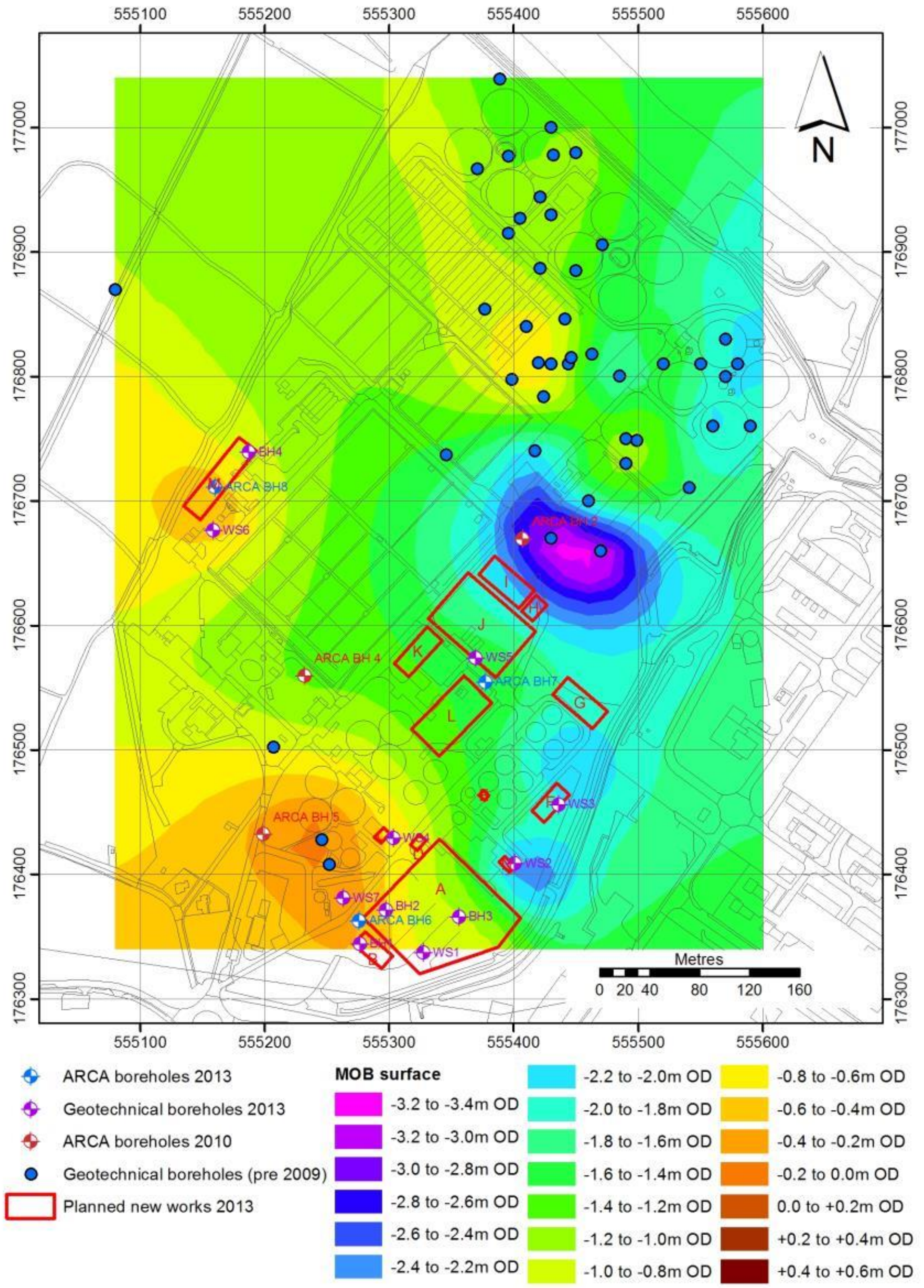

Figure 15: Modelled surface of the MOB.

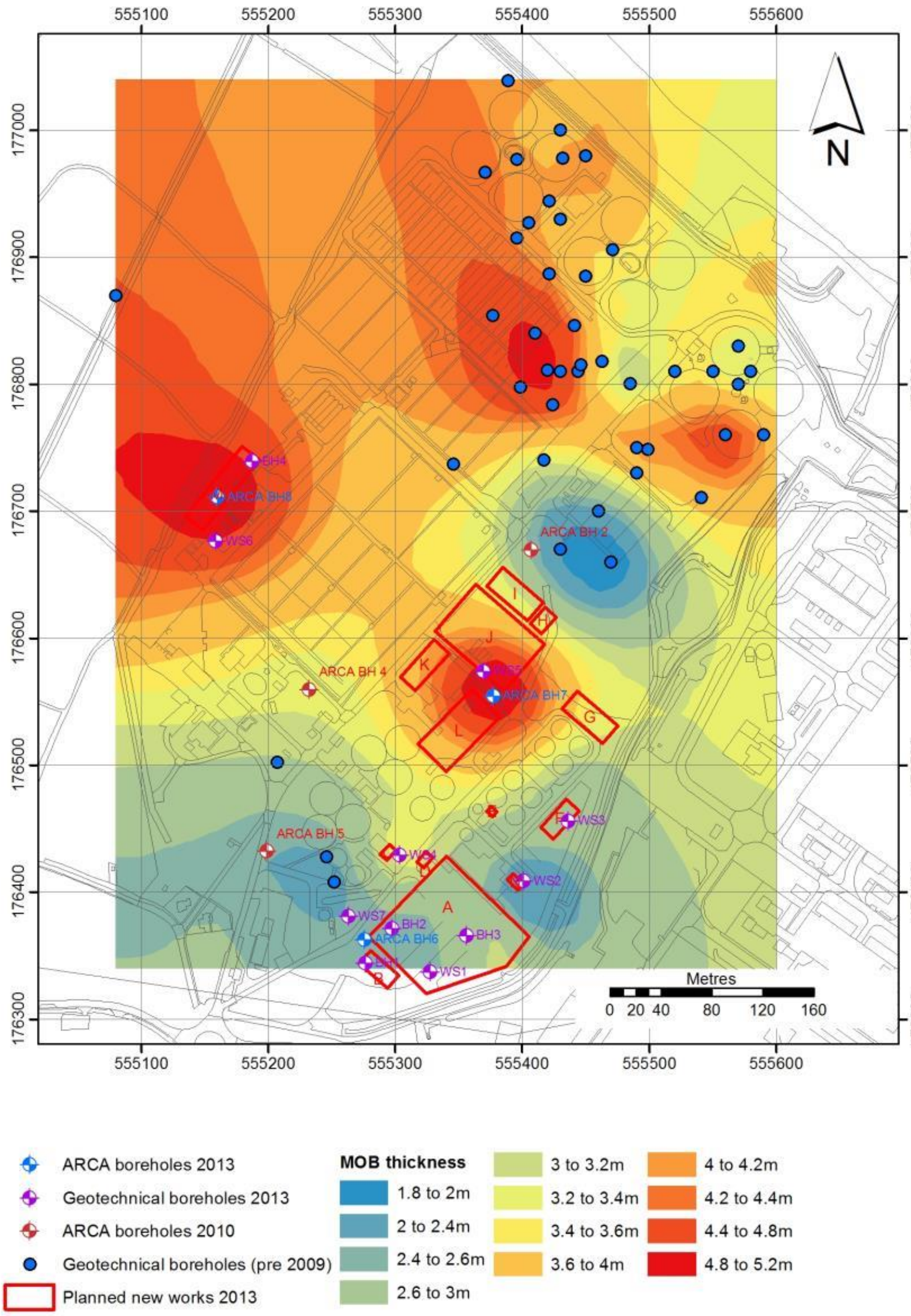

Figure 16: Modelled thickness of the MOB.

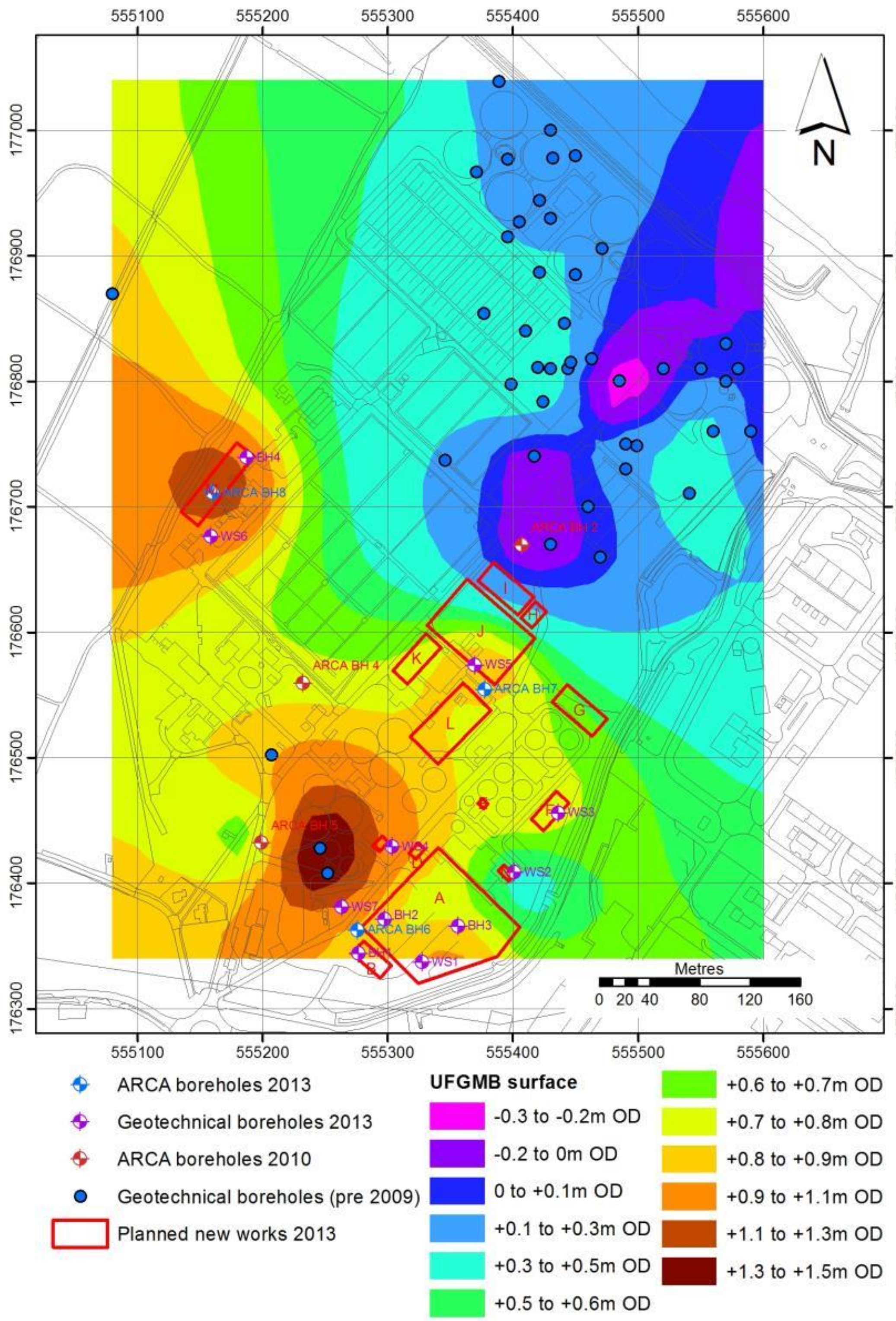

Figure 17: Modelled surface of the UFGMB.

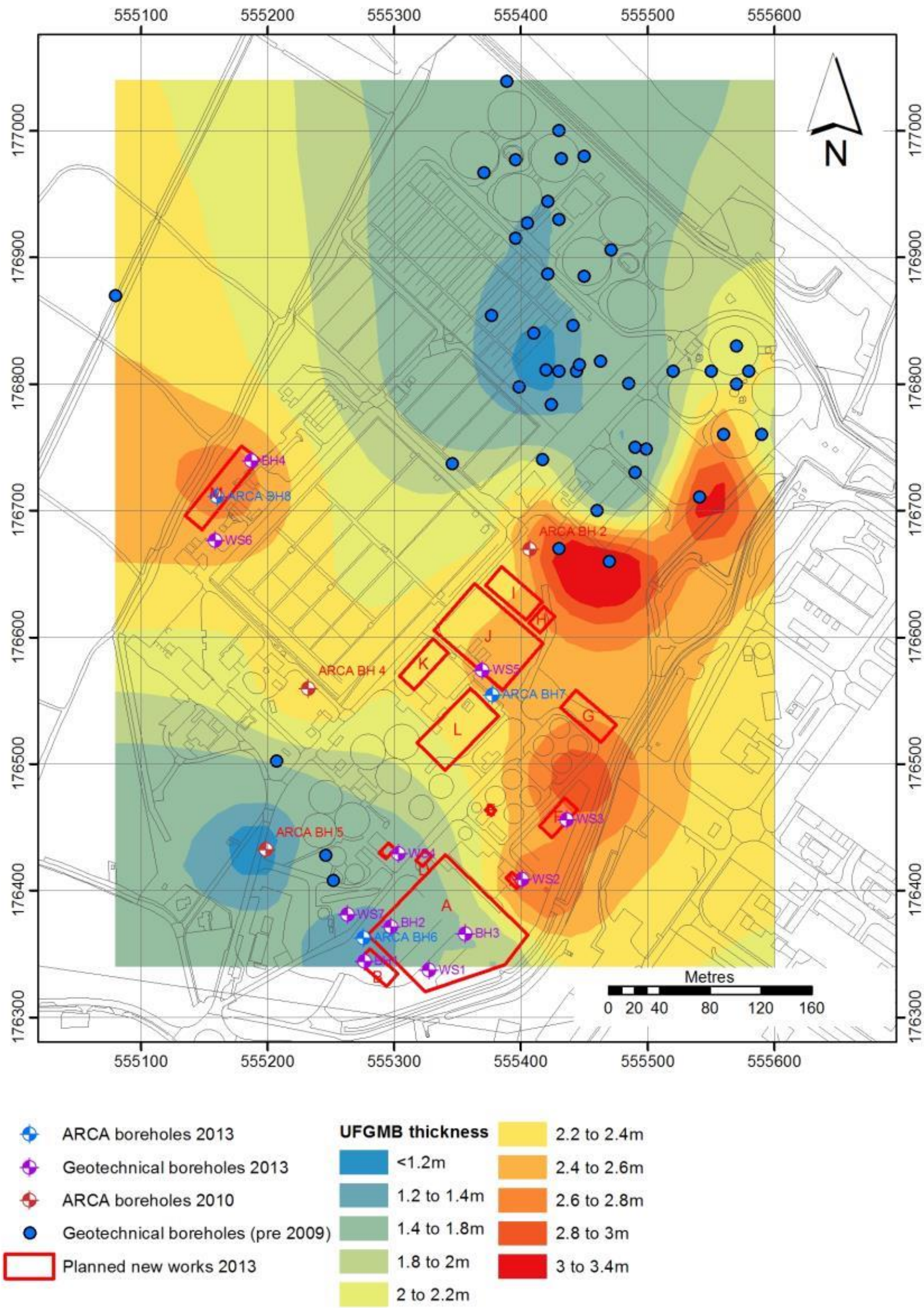

Figure 18: Modelled thickness of the UFGMB.

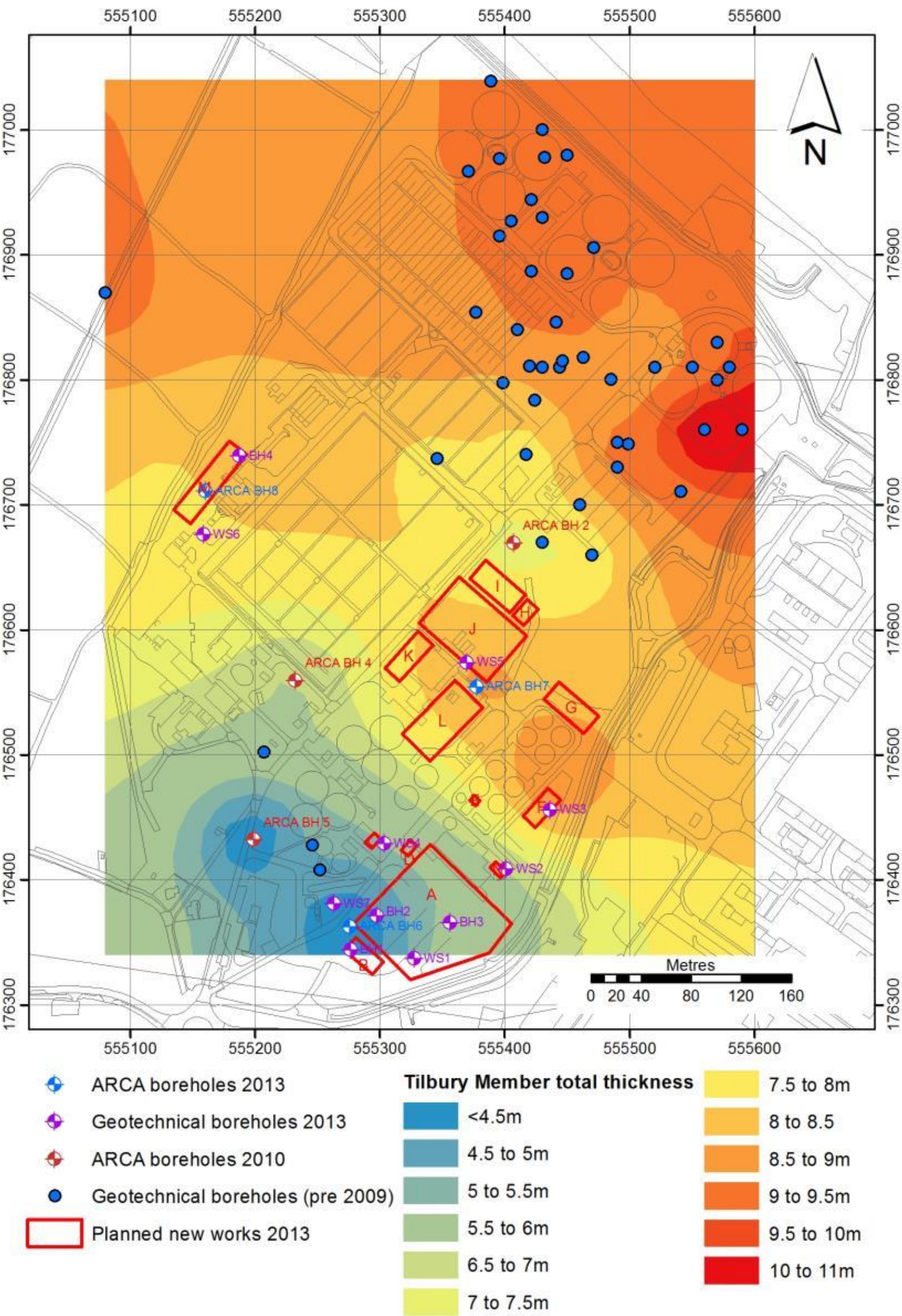

Figure 19: Modelled total thickness of the Tilbury Member (LFGMB, MOB and UFGMB).

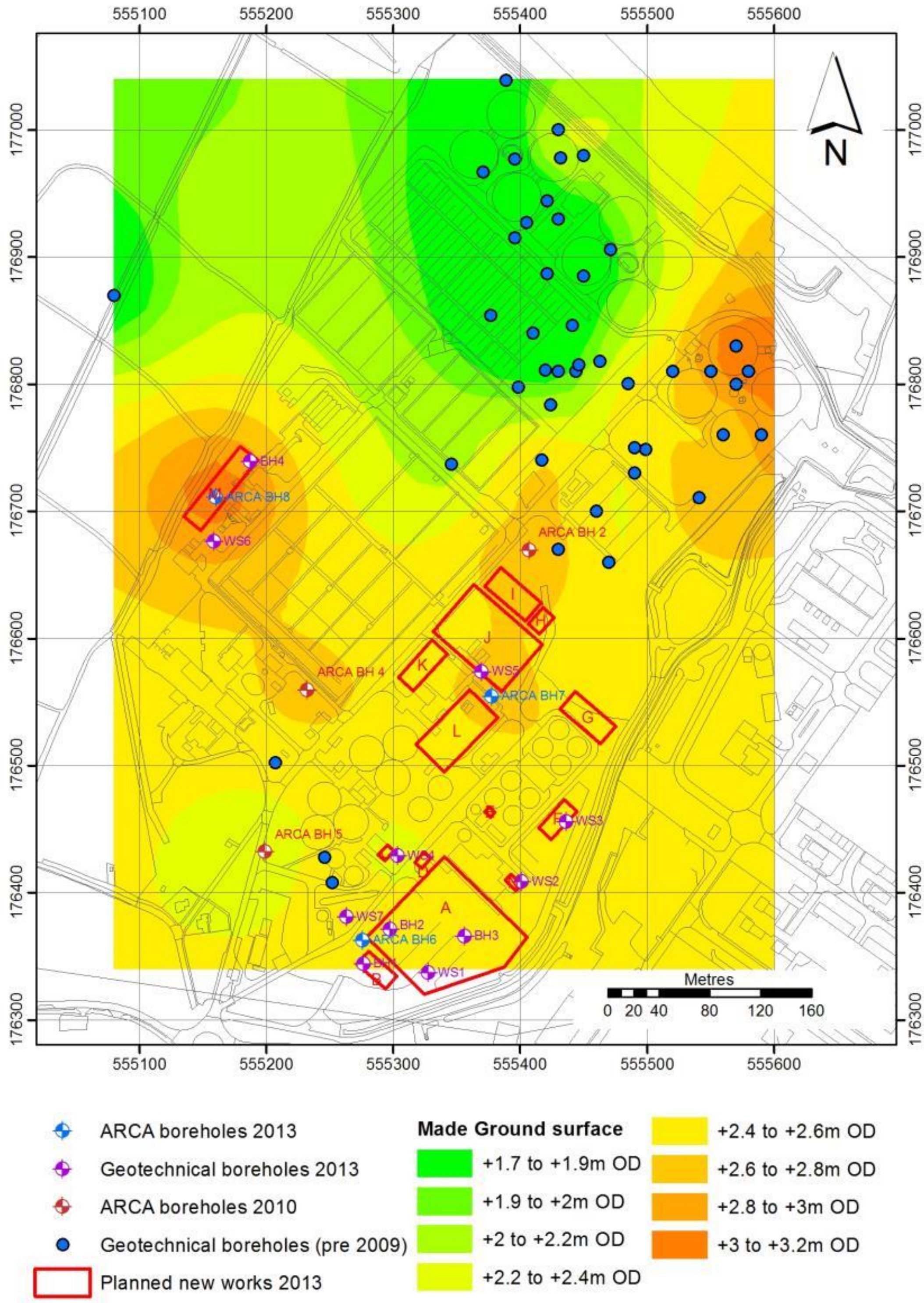

Figure 20: Modelled surface of the Made Ground.

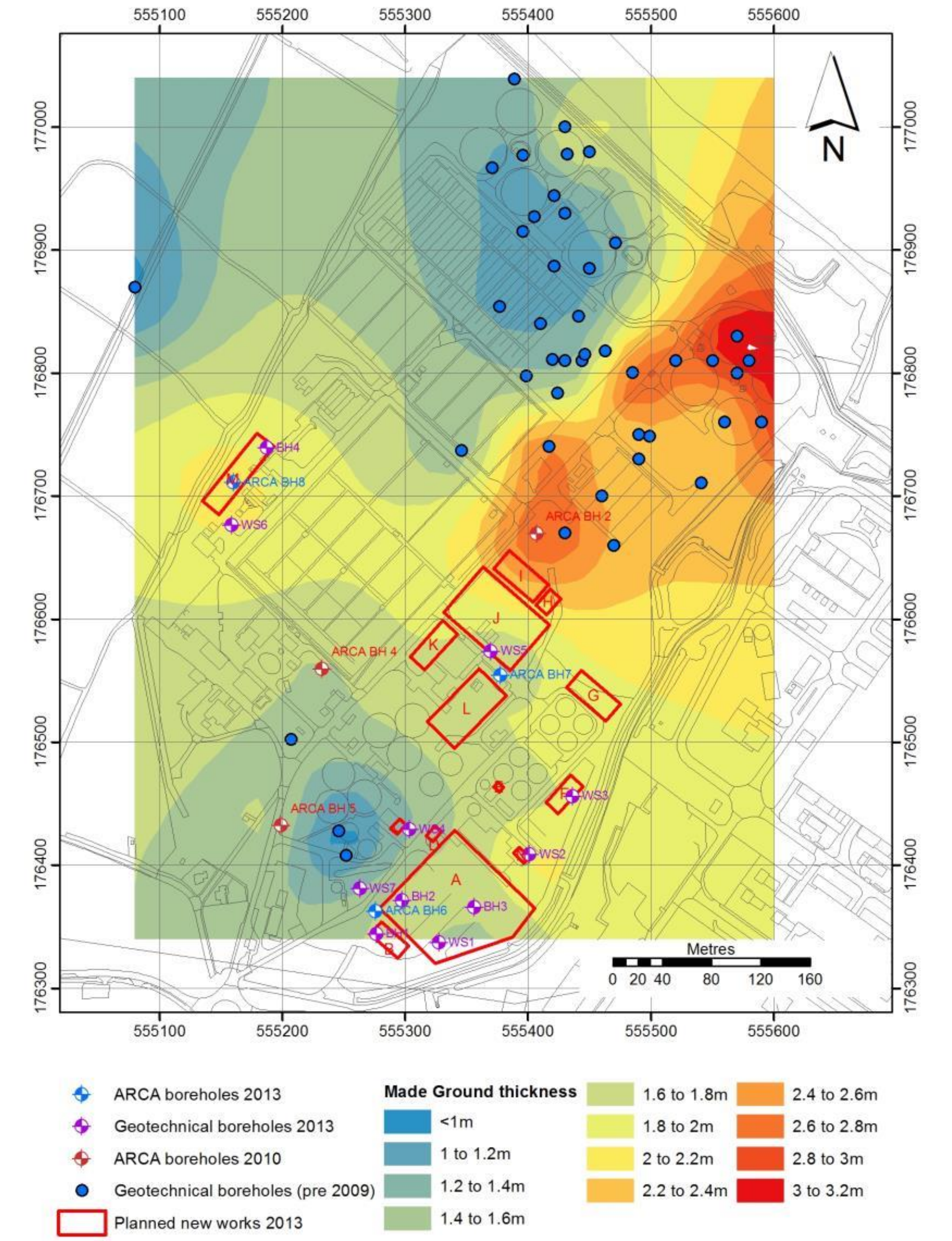

Figure 21: Modelled thickness of the Made Ground.

7. DISCUSSION

7.0.1 In this section the aims of the Phase 3 geoarchaeological and palaeoenvironmental project as outlined in Section 1.6 are addressed using the data presented in Section 3-6. However, the data have significance beyond those aims insofar as they relate to vegetation history. Additional sub-sections therefore discuss evidence for vegetation communities on the Long Reach site in the context both of the wider Lower Thames and southern England.

7.1 Sea level history

7.1.1 The diatom analysis was carried out in order to reconstruct the relationship of the site with changing sea levels. Samples were selected from the interface between each peat and mineral unit to identify evidence for changes in salinity.

7.1.2 Two samples extracted from the interface between the Shepperton Gravel and overlying peat contained no diatom remains and thus no relative sea level signature was derived. The concentration and preservation of pollen was also limited in these samples, but the few grains preserved do not include potential saline indicators such as *Chenopodium* type (e.g. *Suaeda maritima* – thrift), *Plantago maritima* (sea plantain) or *Armeria maritima* (thrift).

7.1.3 The diatom assemblages from the interface between the main peat stratum of the MOB and overlying mineral strata within the MOB show a declining percentage of oligohalobous indifferent taxa with broad environmental (including salinity) tolerance. There is an increasing percentage at -1.88m OD, of polyhalobous and mesohalobous diatoms that are associated with coastal and estuarine habitats. In addition, halophilous diatoms, that are also aerophilous species, become a significant component of the assemblage. These data indicate a positive relative sea level tendency, while in combination with the lithological data they suggest a conformable contact meaning that the latter can be used as sea level index point.

7.1.4 At the interface between the mineral sediments and first of the thinner reed peats within the upper part of the MOB (-1.11m and -1.03m OD), the diatom assemblages show an increasing percentage of oligohalobous indifferent taxa, most of these freshwater diatoms have broad environmental tolerances. The percentages of halophilous and mesohalobous taxa decline at -

1.03m OD. Polyhalobous diatoms, which represent 20% of the assemblage at -1.11m are absent at -1.03m OD.

7.1.5 In the uppermost four samples of the ARCA BH6 sequence from -0.71m to -0.35m OD, Oligohalobous indifferent diatoms decrease from a maximum of 87% at -0.71m to 12% at -0.35m OD. The decline in freshwater taxa is accompanied by increases in mesohalobous diatoms, which increase from about 5% to 42%, and polyhalobous taxa which increase from 2% to 23% in this part of the sequence. There is a marked difference between the high percentages of oligohalobous indifferent diatoms in the two lower samples in this part of the sequence whilst mesohalobous diatoms are present in relatively low numbers. This is followed by a switch to high percentages of mesohalobous taxa with a marked decline in oligohalobous indifferent diatoms in the top two samples. The indication of increasing salinity and marine influence in the top two samples (-0.51m and -0.35m OD) is also shown by the higher percentages of halophilous to oligohalobous indifferent, halophilous, and mesohalobous to halophilous groups. These include a range of shallow water, non-planktonic diatoms as well as some planktonic species.

7.1.6 The diatom assemblages from ARCA BH6 therefore reflect four phases of environmental and salinity changes. At the interface between the main peat stratum within the MOB and the overlying mineral layers there appears to be a period of increasing salinity. Based on the age vs depth model generated for ARCA BH6 this inundation of the tidal marsh appears to have occurred at *c.* 3310-3200 cal BP (i.e. during the Middle Bronze Age). Higher up in the MOB, in the two samples at -1.11m and -1.03m OD (modelled dates *c.* 2200-2100 cal BP and *c.* 2090-1980 cal BP, i.e. during the Late Iron Age/Roman period) there is the establishment of freshwater diatoms and decline of marine taxa, but with continuing estuarine input. The dominant oligohalobous indifferent component seen at both -0.71m and -0.63m OD shows a marked decline. Increasing salinity and hence higher relative sea level during the Early Medieval to Medieval period is shown by the mesohalobous, polyhalobous and halophilous halobian groups that dominate the top of the sequence (UFGMB) at -0.51m and -0.35m OD.

7.2 Vegetation history

7.2.1 Multiple palaeoenvironmental investigations have been carried out on the Lower Thames Valley floodplain between central

London and the Erith / Aveley Marshes (e.g. Sidell *et al.*, 2000; Wilkinson *et al.*, 2000; Seel, 2001; Batchelor, 2009; Branch *et al.*, 2012). By comparison, only a limited number of similarly detailed studies have been carried out on the floodplain further to the east, and hence towards the outer estuary. In the latter area the key work is still that of Devoy (1979), which includes the New Dartford Tunnel, Stone Marshes, West Thurrock, Broadness Marshes and Tilbury sites. Only a few subsequent investigations have been carried out, including at Tilbury (e.g. Batchelor, 2009; Batchelor *et al.*, 2013) and along the Mar Dyke (e.g. Wilkinson *et al.*, 1988) and Darenth (e.g. Batchelor *et al.*, in press) tributaries. By comparison therefore, the environmental history of this stretch of the river is less well understood than further upstream. The record from Long Reach thus both enhances knowledge and understanding of the environmental history of this stretch of the river, but also provides a useful comparison with the records from the new Dartford Tunnel and Stone Marsh sites which are located nearby.

7.2.2 At Long Reach, pollen analysis focused on those parts of the lithostratigraphic sequence most likely to represent semi-terrestrial or terrestrial environments on the wetland; i.e. the peats. Whilst this prevented a reconstruction of vegetation history through the complete sedimentary sequence as carried out and advocated by Allen and Scaife (2000), it permitted a high resolution analysis of those parts studied.

7.3 Wetland vegetation

7.3.1 During the earliest stages of peat formation, which commenced around 6410-6300 cal BP (late Mesolithic / early Neolithic; LPAZ LRBH6-1 and 2), the dominance of alder and sedges with willow, herbs and aquatic taxa indicate that the Long Reach area consisted of alder fen carr, with areas of still or standing freshwater. It is possible that other fen woodland taxa such as oak, birch, ash and hazel also occupied the peat surface. This interpretation is enhanced by the records from Stone Marsh, the New Dartford Tunnel, and the West Thurrock Marshes which contain high pollen counts and macrofossil remains of alder, oak and hazel within various peats dated from at least 8000 to 6300 cal BP (Devoy, 1979). Towards the very base of the Long Reach ARCA BH6 sequence, pollen concentration is very low and the grains that were found are in a poor state of preservation. This might be a reflection of oxidising conditions and desiccation as a consequence of a fluctuating water table.

7.3.2 Retrogressive succession and the growth of tall herb (specifically grass/sedge) and fern swamp are indicated at the transition into LPAZ LRBH6-3 (i.e. at the boundary between the LFGMB and the MOB). During the subsequent zone LPAZ LRBH6-4, further changes in wetland vegetation are indicated by a shift from tall herb and fern swamp to sedge fen. Throughout both zones, alder carr woodland continued to grow, but probably only on drier areas of the floodplain such as towards the floodplain/dryland interface. The transition from alder carr and subsequent growth of herbaceous/fern swamp and sedge fen has affinities with the records from Stone Marsh and the Dartford Tunnel, although the precise pattern of vegetation is not the same. This is most likely a reflection of varying peat surface hydrological conditions between the different areas of investigation. The initial shift in peat surface vegetation is suggestive of a shift from dry to wet conditions, most likely driven by an increase in relative sea level rise. However, high values of microcharcoal and potentially, ferns are strongly suggestive of natural or anthropogenic burning around the time of the decline in alder fen carr. Thus, whilst changes in vegetation and hydrology are evident on the peat surface, along with an apparent episode of natural/anthropogenic burning, it is not possible to establish the precise cause and effect relationships of these events. This finding is similar to that recently recorded at the London Distribution Park in Tilbury (Batchelor *et al.*, 2013).

7.3.3 The final change in vegetation on the wetland commenced towards the very top of the main peat unit within the MOB, and continued within the two thinner upper peats (LPAZ LRBH6-5). During this period, alder woodland declined further and a stronger shift towards sedge fen and reed swamp communities is indicated together with the development of saltmarsh communities. This shift coincides with the evidence for increasing salinity indicated by the diatoms (see Section 7.1.6).

7.4 Dryland vegetation

7.4.0 The ^{14}C-dated palaeoenvironmental records from Long Reach ARCA BH6 indicate that during LPAZ-1 and 2 mixed lime and oak woodland, and hazel shrubland dominated with ash, elm and birch. These warmth-loving trees, especially elm and lime, became established during a period of Early Holocene climatic amelioration, forming a mixed deciduous forest ecosystem. This forest would have been present throughout the Lower Thames Valley, and probably formed excellent areas for human occupation, with rich plant and animal resources, including hazel nuts and acorns, and probably *Cervus elaphus* (red deer) and *Bos primigenius* (aurochs) (see Thomas and Rackham, 1996; Sidell *et al.,* 2002).

7.4.1 The elm decline

7.4.1.1 A decline in *Ulmus* is recorded both towards the bottom and top of LPAZ LRBH6-3, which may be representative of a reduction in the elm population. The decline of elm is well-documented in pollen-stratigraphic diagrams across north-western Europe, and represents arguably one of the most significant changes in vegetation composition and structure during this time. In Britain and the Lower Thames Valley, it is recorded between 6343 and 5290 cal BP (Parker *et al.*, 2002; Batchelor *et al.*, in press). The decline at Long Reach is not directly dated and not well pronounced, but was recorded between 5920-5330 cal BP at Stone Marsh site and between 6450-6010 cal BP at the New Dartford Tunnel. Age estimates for the elm decline (base of LPAZ LRBH6-3) at Long Reach based on the linear age vs depth model (Figure 4) range between *c.*5120 and 5030 cal BP, i.e. somewhat later than that seen at the nearby sites.

7.4.1.2 An exhaustive literature discusses the potential causes of the elm decline which include: (1) climate change to cooler conditions (e.g. Smith, 1981); (2) soil deterioration (Peglar and Birks, 1993), (3) competitive exclusion (e.g. Huntley and Birks, 1983; Peglar and Birks, 1993); (4) human interference with natural vegetation (e.g. Scaife, 1988; Lamb and Thompson, 2005), and (5) disease (e.g. Perry and Moore, 1987; Girling, 1988). The two most strongly argued causes for the decline are human interference with natural vegetation succession and disease; with a combination of the two more recently advocated (e.g. Parker *et al.*, 2002).

7.4.1.3 At Long Reach, the palaeoenvironmental records provide no data contributing to the argument of decline caused by climate change. Similarly, whilst the decline was likely at least in part caused by the spread of disease, support for this argument is based upon finds of the insect *Scolytus scolytus* which carries the causal fungus *Ceratocystis* (*Ophiostoma*) *ulmi*; this beetle has rarely been recorded in the British Isles and was not noted at Long Reach. The decline does however correlate with large numbers of microcharcoal particles, which whilst at least in part representative of burning might also be related to Early Neolithic episodes of temporary land clearance for agricultural purposes. No contemporaneous evidence of human activity is recorded, but on the basis of the microcharcoal and increasing light-loving hazel, it cannot be excluded as a potential cause of the decline nearby. Multiple records elsewhere in the Lower Thames Valley, also indicate the role of burning and/or human activity at the time of the Neolithic elm decline including the London Distribution Park (Tilbury North; Batchelor *et al.*, 2013), Mar Dyke (Wilkinson *et al.*, 1988) and Golfers Driving Range (Beckton; Batchelor *et al.*, in prep).

7.4.1.4 The records from New Dartford Tunnel and Stone Marsh indicate the interaction of different factors at the time of the elm decline. In the New Dartford Tunnel sequence for example, the decline corresponds with a transition from mineral deposits to peat formation indicating environmental changes taking place on the floodplain. This process of 'paludification' is likely to have at least contributed towards a reduction in elm populations by impacting upon trees growing at the dryland-wetland interface, both directly, and by introducing competition between different species. In addition, the contemporaneous wide-scale development of dense fen carr woodland associated with paludification undoubtedly also caused changes in pollen recruitment and may have affected the representation of elm pollen. The effects of paludification have also been proposed as a cause of the *Tilia* (lime) woodland decline at some sites during the Late Neolithic and Bronze Age (Waller, 1994a; Grant *et al.*, 2011).

7.4.1.5 Another strongly advocated hypothesis is that a combination of factors caused the elm decline, on the basis that any single factor is unlikely to have had such widespread and catastrophic effects (see Girling and Grieg, 1985; Peglar and Birks, 1993; Parker *et al.*, 2002; Lamb and Thompson, 2005; Batchelor et al., in press). The combined evidence from Long Reach, Stone Marsh and the New Dartford Tunnel is strongly supportive of this hypothesis since at each site, the decline occurs at a different time and contains evidence for different causal factors.

7.4.2 The colonisation and decline of yew

7.4.2.1 As previously outlined, yew has recently been recognised as a co-dominant component of the alder dominated fen carr woodland in the Lower Thames Valley (e.g. Seel, 2001; Batchelor, 2009). Similar findings have been made in the Somerset Levels (e.g. Beckett & Hibbert, 1979; Coles & Hibbert, 1968), East Anglian Fens (Waller, 1994b), Ireland (Delahunty, 2002) and Belgian coastal lowlands (Deforce and Bastiaens, 2007).

7.4.2.2 At present, pollen and macrofossil evidence indicate the growth of yew on a relatively dry peat surface along a confined stretch of the Lower Thames Valley floodplain between the East India Docks to the west (Pepys, 1665) and Purfleet/Erith Marshes (Wilkinson and Murphy, 1995; Seel, 2001) to the east, from approximately 5000-4000 cal BP (Batchelor, 2009). However, this is unlikely to be a true representation of the distribution of yew on the floodplain surface, but rather of the limited concentration of developer-funded palaeoenvironmental investigations eastward of the Purfleet/Erith Marshes.

7.4.2.3 During the latter stages of the formation of the main peat unit within the MOB at Long Reach, small quantities of yew pollen are recorded in LPAZ LRBH6-4. Similar findings were not made in the records from Stone Marsh and New Dartford Tunnel (Devoy, 1979), most likely as a consequence of the widely acknowledged difficulties in correctly identifying the pollen grain (e.g. Srodon, 1978; O'Connell, 2005). Despite the low concentrations recorded at Long Reach, previous investigations demonstrate this can still indicate the nearby presence of the tree; for example at Crossness Sewerage Works, little or no pollen was recorded but trees were observed in the archaeological section (Batchelor *et al.*, 2009). Potential factors specific to yew that might cause this include the fact that yew does not reach sexual maturity until it is around 70 years of age (thus not producing seeds/pollen until this time; Seel, 2001) and that it is a dioecious tree, meaning that trees are either male or female as opposed to both (thus an individual tree may not produce pollen; Thomas and Polwart, 2003).

7.4.2.4 The new record from Long Reach therefore increases knowledge and understanding of the distribution of yew across the Lower Thames Valley floodplain. However, it is not anticipated that yew was growing on the peat surface during the period as the palaeoenvironmental evidence indicates the surface was too wet. It is more likely that yew formed a component of the mixed deciduous woodland on the dryland, potentially even taking advantage of glades caused by the decline of elm. This interpretation is enhanced by the present day preference of yew for dry and calcareous-rich soils suggesting that yew probably expanded on both the dryland and peat surface during the later Neolithic.

7.4.3 The decline of dryland woodland

7.4.3.1 From approximately 3610-3460 cal BP a marked decrease in dryland woodland taxa (e.g. *Quercus* and *Tilia*) occurs. The decline in woodland on the wetland and dryland is therefore approximately contemporaneous, an occurrence analogous with many other sites across the Lower Thames Valley. Problems related to the taphonomy of pollen from wetland and dryland environments all inhibit the interpretation of pollen data, and the ability to confidently reconstruct vegetation succession and causes of environmental change on dryland, however, the occurrence of an array of herbaceous pollen taxa including cf *Cereale* type which most likely originate from the dryland, with other taxa such as Poaceae, *Chenopodium* type and Lactuceae may originate from a number of different environments, including the dryland, suggesting Bronze Age land clearance for settlement and/or farming purposes was taking place at this time.

7.4.3.2 Nevertheless, the contemporaneous nature of the decline in woodland on both the wetland and dryland is striking and suggests a strong link between the two environments and possible causes. Indeed, it is considered probable that the increased rate of relative sea level (RSL) rise that brought about environmental change on the wetland, also contributed to the decline of mixed deciduous woodland on the dryland in two different ways. Firstly, RSL rise may have caused the expansion of wetland onto areas of former dryland, and/or the saturation of dryland soils. This would have caused the retreat of dryland woodland away from the sampling point. Secondly, the wetter conditions and estuarine inundation that caused the eventual abandonment of the wetland by Bronze Age people, most likely led to the concentration of anthropogenic activity (and thus clearance) on the neighbouring dryland edge. There seems little doubt that these RSL driven processes could have influenced the rate of woodland decline on the dryland; however, the precise temporal and spatial relationships between RSL change, soil deterioration, human activity and dryland woodland decline remain very difficult to measure.

8. CONCLUSIONS

8.1 The geoarchaeological project at Long Reach, Dartford has passed through three phases of work (involving an initial phase of fieldwork and desk-based research, a phase of palaeoenvironmental assessment, and finally further fieldwork and the palaeoenvironmental analysis presented here) and has lasted three and a half years.

8.2 The records from Long Reach provide high resolution indication of environmental changes in a section of the Lower Thames estuary where previous investigations have been limited. Assessment and analysis of multiple sequences from the site has revealed a consistent sequence of environmental changes at the site, relating both to changes in the rate of RSL rise and to changes in the local and regional vegetation cover. Whilst direct evidence for localised human activity at the site is restricted, the litho- and biostratigraphic records from Long Reach reveal a series of environmental changes which may have come about due to the complex interaction between both human activity (i.e. the occurrence of microcharcoal and evidence for Bronze Age cultivation) and natural environmental change (i.e. changes in RSL).

8.3 Publication of the geoarchaeological and palaeoenvironmental evidence from Long Reach would establish the site as an important Holocene sequence for sea level and vegetation change in that part of the Lower Thames Valley. The publication and its significance will therefore be the most demonstrable evidence for the project's success.

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9.3 Except where indicated the text presented in this report has been written by Phil Stastney and Rob Batchelor. The project was managed for ARCA by Keith Wilkinson.

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APPENDIX 1 – BOREHOLE LOCATIONS AND LITHOSTRATIGRAPHY

Borehole	Easting	Northing	Elevation	Total Depth (m)
ARCA BH6	555275.96	176364.03	2.35	8.00
ARCA BH7	555378.18	176553.17	2.71	11.00
ARCA BH8	555159.13	176711.03	3.28	11.00

Borehole	Top (m)	Base (m)	Lithology	Comments
ARCA BH6	0.00	2.00	No Recover	---
	2.00	2.73	Homogeneous Grey Blue Silt/Clays	5Y5/1 Grey silt/clay with occasional black staining. Diffuse boundary to:
	2.73	2.82	Reed Peat	2.5Y4/1 Dark grey well humified reed peat with frequent granular sized reed fragments. Sharp boundary to:
	2.82	2.97	Homogeneous Grey Blue Silt/Clays	2.5Y5/2 Greyish brown silt/clay with frequent granular sized peat fragments (reed). Diffuse boundary to:
	2.97	3.00	Homogeneous Grey Blue Silt/Clays	5Y5/1 Grey silt/clay with occasional granular- sized peat fragments and black humic stains.
	3.00	3.12	No Recover	---
	3.12	3.15	Homogeneous Grey Blue Silt/Clays	5Y5/1 Grey silt/clay with occasional granular- sized peat fragments and black humic stains.
	3.15	3.49	Reed Peat	2.5Y3/2 Very dark greyish brown well humified reed peat with rare granular-sized reed fragments. Diffuse boundary to:
	3.49	4.26	Homogeneous Grey Blue Silt/Clays	5 Y 5/1 Grey silt/clay with occasional black humic stains. Diffuse boundary to:
	4.26	4.77	Reed Peat	7.5 YR 2.5/3 Very dark brown well humified reed peat with rare granular-sized fragments of reed and frequent sand-sized fibres. Sharp boundary to:

Borehole	Top (m)	Base (m)	Lithology	Comments
ARCA BH6 cont.	4.77	6.00	Wood Peat	7.5 YR 3/4 Dark brown moderately well humified wood peat with granular to small pebble-sized wood fragments and frequent sand-sized fibres. Sharp boundary to:
	6.00	6.20	No Recover	---
	6.20	6.54	Reed Peat	7.5 YR 2.5/2 Very dark brown well to very well humified at base reed peat with frequent to rare at base sand-sized fibres. Rare mineral grains at base. Diffuse boundary to:
	6.54	7.00	Fluvial Sand	5 Y 5/2 Olive grey well sorted fine to medium sand.
	7.00	7.14	No Recover	---
	7.14	8.00	Fluvial Sand	5 Y 5/2 Olive grey well sorted fine to medium sand. White chalk mud lamina at 7.38m and occasional angular to well-rounded flint clasts towards base.
ARCA BH7	0.00	2.53	Made Ground	---
	2.53	4.00	Homogeneous Grey Blue Silt/Clays	5 Y 5/1 Grey silt/clay with rare granular-sized angular rock fragments towards top. Rare black humic stains towards base.
	4.00	4.17	Homogeneous Grey Blue Silt/Clays	5 Y 5/1 Grey silt/clay with rare black humic stains towards base. Diffuse boundary to:
	4.17	4.67	Reed Peat	2.5 Y 3/2 Very dark greyish brown reed? peat, moderately well humified with frequent sand to granular-sized fragments. Sharp boundary to:
	4.67	4.74	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand-sized peat fragments and black humic staining. Diffuse boundary to:
	4.74	4.76	Reed Peat	7.5 YR 3/3 Dark brown reed peat, moderately well humified with frequent sand to granular-sized fragments. Diffuse boundary to:
	4.76	4.84	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand-sized peat fragments and black humic staining. Sharp boundary to:
	4.84	5.61	Reed Peat	10 YR 3/2 Very dark greyish brown reed peat, moderately well humified with frequent sand to granular-sized fragments. Diffuse boundary to :

Borehole	Top (m)	Base (m)	Lithology	Comments
ARCA BH7 cont.	5.61	5.94	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments. Diffuse boundary to:
	5.94	6.00	Wood Peat	2.5 Y 2.5/1 Black peat, moderately well humified with rare granular-sized wood fragments and frequent sand to granular-sized fibres and fragments.
	6.00	6.15	No Recover	---
	6.15	6.86	Wood Peat	10 YR 3/2 Very dark greyish brown peat, moderately well humified with rare pebble-sized wood fragments and frequent sand to granular-sized fibres and fragments.
	6.86	7.00	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments.
	7.00	7.20	No Recover	---
	7.20	7.30	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments. Diffuse boundary to:
	7.30	7.75	Wood Peat	10 YR 3/2 Very dark greyish brown peat, moderately well humified, with rare pebble-sized wood fragments and frequent sand to granular-sized fibres and fragments. Sharp boundary to:
	7.75	8.00	Homogeneous Grey Blue Silt/Clays	2.5 Y 4/1 Dark grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments.
	8.00	8.20	No Recover	---
	8.20	8.50	Homogeneous Grey Blue Silt/Clays	2.5 Y 5/1 Grey silt/clay with frequent granular to pebble-sized wood fragments towards base. Diffuse boundary to:
	8.50	8.65	Wood Peat	5 YR 3/2 Dark reddish brown poorly humified wood peat with frequent granular to pebble-sized fragments. Diffuse boundary to:
	8.65	9.00	Homogeneous Grey Blue Silt/Clays	2.5 Y 5/1 Grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments.
	9.00	9.14	No Recover	---

Borehole	Top (m)	Base (m)	Lithology	Comments
ARCA BH7 cont.	9.14	9.72	Homogeneous Grey Blue Silt/Clays	2.5 Y 5/1 Grey silt/clay with occasional sand to granular-sized peat fragments and rare pebble-sized wood fragments. Diffuse boundary to:
	9.72	9.89	Wood Peat	5 YR 3/2 Dark reddish brown moderately well humified wood peat with frequent granular to pebble-sized fragments. Sharp boundary to:
	9.89	10.00	Homogeneous Grey Blue Silt/Clays	2.5 Y 5/1 Grey silt/clay with rare pebble-sized wood fragments. Diffuse boundary to:
	10.00	10.36	No Recover	---
	10.36	10.68	Homogeneous Grey Blue Silt/Clays	5 Y 5/1 Grey (blue/green) silt/clay with occasional fine sand-sized mineral grains and rare pebble-sized wood fragments. Diffuse boundary to:
	10.68	11.00	Fluvial Gravel	5 Y 5/1 Grey (blue/green) poorly sorted sandy gravel of granular to pebble- sized angular to well-rounded flint clasts.
ARCA BH8	0.00	2.00	No Recover	---
	2.00	2.48	Made Ground	---
	2.48	3.00	Reed Peat	5 Y 2.5/1 Black well humified peat- possible modern contamination-wood, unknown clasts-and hydrocarbon smell.
	3.00	3.42	Homogeneous Grey Blue Silt/Clays	2.5 Y 3/1 Very dark grey silt/clay with occasional to frequent granular-sized plant fibres. Gradual boundary to:
	3.42	4.95	Homogeneous Grey Blue Silt/Clays	5 Y 5/1 Grey silt/clay with occasional black humic staining increasing towards base.
	4.95	5.00	Reed Peat	2.5 Y 3/2 Very dark greyish brown read peat, poorly humified.
	5.00	5.15	No Recover	---
	5.15	5.21	Reed Peat	2.5 Y 3/2 Very dark greyish brown read peat, poorly humified. Sharp boundary to:
	5.21	5.94	Wood Peat	7.5 YR 3/2 Dark brown moderately well humified wood peat with rare pebble-sized wood fragments.
	5.94	6.00	Homogeneous Grey Blue Silt/Clays	5 Y 4/1 Dark grey silt/clay with frequent granular-sized wood fragments.
	6.00	6.13	No Recover	---

Borehole	Top (m)	Base (m)	Lithology	Comments
ARCA BH8 cont.	6.13	6.52	Homogeneous Grey Blue Silt/Clays	5 Y 4/1 Dark grey silt/clay with frequent granular-sized wood fragments and rare cobble-sized clast. Gradual boundary to:
	6.52	6.78	Wood Peat	7.5 YR 4/3 Dark brown well humified wood peat with occasional granular to pebble-sized wood fragments. Sharp boundary to:
	6.78	7.00	Wood Peat	7.5 YR 2.5/1 Black well humified wood peat with rare granular-sized wood fragment.
	7.00	7.21	No Recover	---
	7.21	8.00	Wood Peat	7.5 YR 3/3 Dark brown (3/1 Very dark grey at base) moderately humified wood peat with occasional pebble-sized wood fragments.
	8.00	8.16	No Recover	---
	8.16	8.23	Wood Peat	7.5 YR 3/1 Very dark grey moderately well humified wood peat with occasional pebble-sized wood fragments. Sharp boundary to:
	8.23	8.76	Homogeneous Grey Blue Silt/Clays	2.5 Y 3/1 Very dark grey silt/clay with frequent coarse sand-sized fibres evenly distributed and frequent granular to pebble-sized wood fragments. Diffuse boundary to:
	8.76	8.93	Reed Peat	5 Y 2.5/1 Black organic mud with rare granular-sized reed fragments and occasional fine sand-sized mineral grains increasing towards base.
	8.93	9.00	Fluvial Sand	5 Y 4/1 Dark grey fine to medium sand.
	9.00	9.65	No Recover	---
	9.65	9.86	Fluvial Sand	5 Y 5/1 Grey fine to medium sand. Sharp boundary to:
	9.86	10.00	Fluvial Gravel	5 Y 6/2 Light olive grey poorly sorted, matrix supported chalk gravel. Granular to pebble-sized subangular chalk clasts and rare rounded flints. Chalk mud matrix with frequent fine sand. Sharp boundary to:
	10.00	10.33	No Recover	---
	10.33	10.83	Fluvial Gravel	5 Y 6/2 Light olive grey poorly sorted, matrix supported chalk gravel. Granular to pebble-sized subangular chalk clasts and rare rounded flints. Chalk mud matrix with frequent fine sand. Sharp boundary to:
	10.83	11.00	Fluvial Sand	5 Y 4/1 Dark grey fine to medium sand.