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Holocene alluvial environments at Barking, Lower Thames Valley (London, UK)

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ABSTRACT

Deposit modelling based on archived borehole logs supplemented by a small number of dedicated boreholes is used to reconstruct the main boundary surfaces and the thickness of the main sediment units within the succession of Holocene alluvial deposits underlying the floodplain in the Barking Reach of the Lower Thames Valley. The basis of the modelling exercise is discussed and the models are used to assess the significance of floodplain relief in determining patterns of sedimentation. This evidence is combined with the results of biostratigraphical and geochronological investigations to reconstruct the environmental conditions associated with each successive stage of floodplain aggradation. The two main factors affecting the history and spatial pattern of Holocene sedimentation are shown to be the regional behaviour of relative sea level and the pattern of relief on the surface of the sub-alluvial, Late Devensian Shepperton Gravel. As is generally the case in the Lower Thames Valley, three main stratigraphic units are recognised, the Lower Alluvium, a peat bed broadly equivalent to the Tilbury III peat of Devoy (1979) and an Upper Alluvium. There is no evidence to suggest that the floodplain was substantially re-shaped by erosion during the Holocene. Instead, the relief inherited from the Shepperton Gravel surface was gradually buried either by the accumulation of peat or by deposition of fine-grained sediment from suspension in standing or slow-moving water. The palaeoenvironmental record from Barking confirms important details of the Holocene record observed elsewhere in the Lower Thames Valley, including the presence of *Taxus* in the valley-floor fen carr woodland between about 5000 and 4000 cal BP, and the subsequent growth of *Ulmus* on the peat surface.

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1. Introduction

For the Lower Thames Valley there are many unpublished records of the Holocene deposits underlying the floodplain. Much of the information is accessible in the borehole archive of the British Geological Survey (BGS; NERC) or in the so-called 'grey literature' – the geological and archaeological reports arising from commercial site investigations. Despite this profusion of site-specific information, there are surprisingly few published accounts of the floodplain deposits, especially downstream from Greenwich; and few attempts to assess the quality of the available data, or to explore the factors that shaped the sedimentary environments and landforms of the Holocene valley floor. These broader problems have been considered in the lower Lea valley by Corcoran et al. (2011) and highlighted by Bates and Whittaker (2004) for the Lower Thames Valley.

Investigation of two sites on the floodplain at Barking (Fig. 1) has provided the opportunity to describe and explain the Holocene alluvial record in the Barking Reach of the Lower Thames Valley through the application of deposit modelling to archived borehole data, supplemented by data from a small number of targeted boreholes. The aim of the present paper is to reconstruct the relief of the valley floor at each stage in its development during the Holocene and to explore the origin of this relief and the way in which it may have influenced the accumulation of alluvial sediments. The sites, at Barking Riverside, and Renwick Road, together with the immediately adjoining land (an area referred to throughout this paper as 'Barking'), cover an area of 277 Ha, occupying *c.* 1.5 km of the north bank the Thames and extending inland *c.* 1.7 km to include an area of Taplow Gravel and the bluff separating the Taplow Gravel from the floodplain. The present ground surface is between 4.0 m and 13.5 m OD, but is entirely artificial, reflecting the presence of variable

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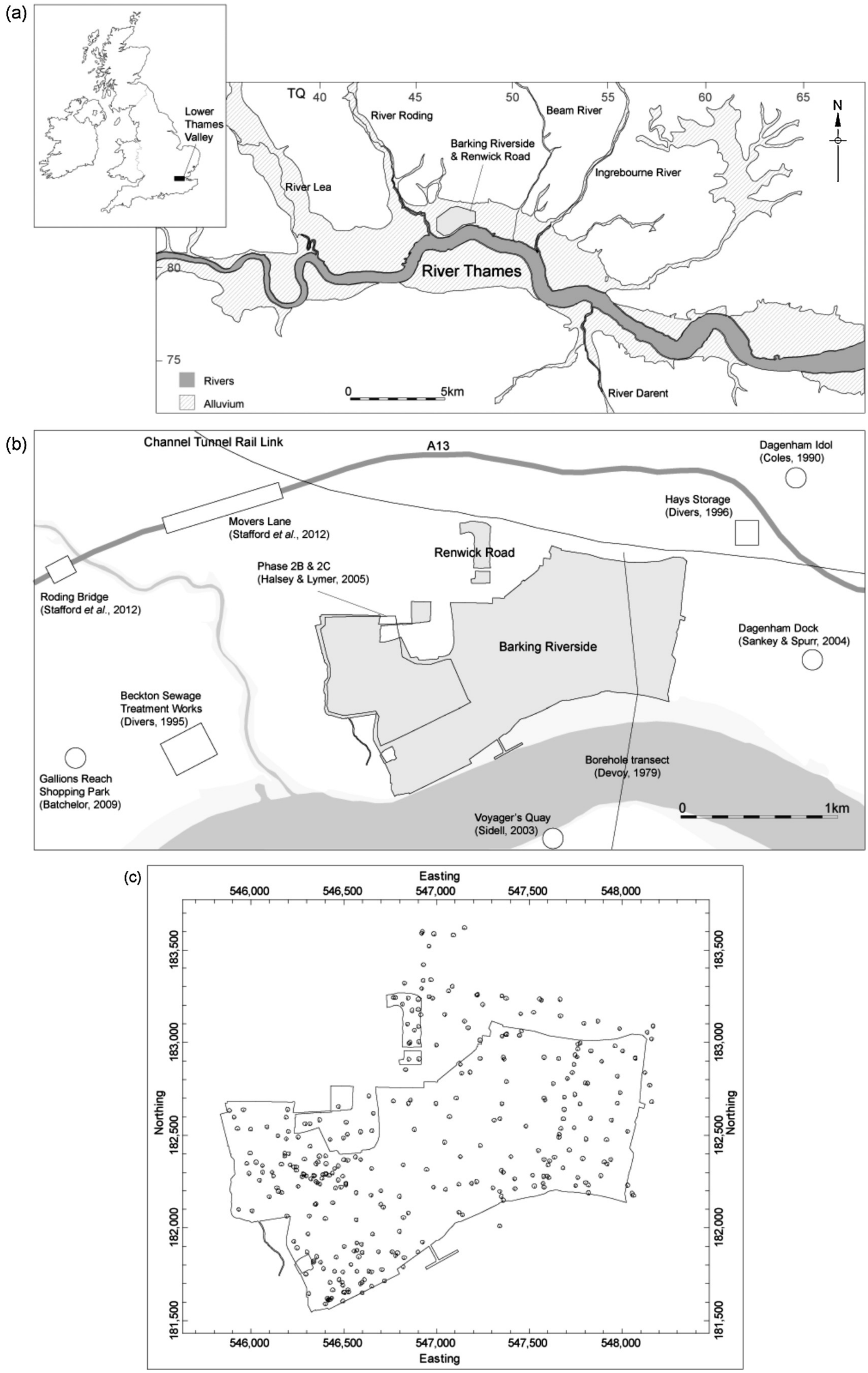

Fig. 1. (a) The Lower Thames Valley (which extends from central London to Tilbury, Mucking and Stanford Le Hope in the East) and location of the Barking Riverside and Renwick Road sites (Coles, 1990); (b) Barking Riverside, Renwick Road and other relevant palaeoenvironmental/archaeological sites; (c) Distribution of boreholes across the two study areas.

thicknesses of Made Ground. The natural floodplain (formerly Barking Level) was probably almost flat and was apparently uninterrupted by any substantial channels or tidal creeks (OS First Series, Sheet 1, 1805). The level of the surface on which the Made Ground rests, based on over 300 borehole and test pit records (mean value 0.03 m OD; σ: 1.38, $n = 323$) provides a good indication of the natural level of the floodplain.

The general arrangement of the Thames floodplain deposits has long been recognised. The sediments form a tripartite sequence comprising: (1) an upper silty-clay unit (termed here the Upper Alluvium); (2) a peat or organic mud (generally equivalent in age to Devoy's (1979) Tilbury III peat; *c.* 6500–3000 cal BP), and (3) a lower, more variable sandy and silty unit (termed here the Lower Alluvium) sometimes including detrital wood, herbaceous plant remains, Mollusca and additional thin peat beds. Less well understood are the factors that control the distribution and development (thickness) of these three units, either within the floodplain or in relation to one another.

Accounts of floodplain deposits in the Barking area (Devoy, 1979; Divers, 1995, 1996; Bates, 1998; Sidell, 2003; Bates and Whittaker, 2004; Halsey and Lymer, 2005; Batchelor, 2009a; Fig. 1) and both upstream and downstream (e.g. Sidell et al., 2000; Wilkinson et al., 2000; Batchelor, 2009b; Branch et al., 2012) confirm the widespread occurrence of this tripartite Holocene alluvial sequence and of the underlying Late Devensian Shepperton Gravel (Gibbard, 1985), the surface of which represents the immediately pre-Holocene floodplain, with gravel bars and islands separated by low-water channels typical of a braided river. These relief features have influenced the distribution of depositional environments throughout the successive stages in the evolution of the Thames floodplain. As Bates and Whittaker (2004) observe, the Shepperton Gravels "... form the template onto which Holocene alluvial and estuarine sedimentation occurred." A key factor throughout the Holocene has been the elevation of the ground surface which determined its susceptibility to inundation with important consequences in terms of sediment accumulation and the distribution of natural habitats and archaeological activity.

The level of the gravel surface beneath the Lower Thames Valley floodplain has been recorded in many places, but local variability and its potential causes along and across the valley floor have never been the subject of detailed investigation. The significance of individual records is therefore usually difficult to assess. The general arrangement of the Shepperton Gravel has been illustrated by Gibbard (1985, Fig. 44; 1994, Fig. 48). He shows the level of gravel high points falling from *c.* 2.0 m OD in the Battersea area to *c.* −10.0 m OD near Mucking. In the same illustrations, the normal height range of the gravel surface in and downstream from London appears to be about 5 m, or exceptionally as much as 10.0 m. Investigations upstream from Barking, in Southwark and Bermondsey (e.g. Allen et al., 2005; Batchelor et al., 2012), have recorded up to 6.3 m of relative relief with high points on upstanding areas of gravel between 0.4 m and 2.67 m OD and the floor of the Bankside palaeochannel at levels down to −3.64 m OD. Similar investigation on the south side of the Thames, in Belvedere (Green et al., unpublished data) recorded gravel 'highs' up to −4.47 m OD with the floors of palaeochannels at levels down to −10.83 m OD, a height range of 6.36 m. Further downstream the gravel surface is less well documented, but in the Tilbury area Devoy (1979, Fig. 28) indicated a level commonly at about −12.0 m OD.

2. Lithostratigraphy and deposit modelling

2.1. Archive and field records

The arrangement of the sediments underlying the Barking area has been reconstructed in this account on the basis of evidence from over 300 archived geotechnical boreholes and test pits (Fig. 3). Of these, 164 were logs supplied by Hyder Consulting from Barking Riverside and 10 by Laing O'Rourke from Renwick Road. A further 29 boreholes were either monitored or put down and recorded in the field by the authors. The remaining records (136) were selected from the BGS borehole archive with a view to having stratigraphic information as evenly distributed as possible across the sites, ideally with at least one borehole in each of the 277 one hectare (100 m) squares into which the site has been divided. In practice however, although the Barking area has been subject to many sub-surface investigations, in 97 of the 100 m squares (35% of the area) no borehole record was available, either because none exists or because access to the information is restricted.

2.2. Deposit modelling

The reconstruction of the sedimentary architecture beneath the floodplain at the Barking site was undertaken using deposit models. The term 'deposit modelling' describes any method employed to depict the sub-surface arrangement of geological deposits, but particularly the use of computer programmes to create contoured maps of contacts between stratigraphic units. However, the reliability of such maps in the study of Holocene alluvial sequences has rarely been evaluated, and in the present account, attention is drawn to this issue and to some of the specific problems.

The first requirement is to classify the recorded borehole sequences into widely identifiable stratigraphic units. At Barking five units were recognised beneath the floodplain: (1) Shepperton Gravel, (2) Lower Alluvium, (3) Peat, (4) Upper Alluvium, (5) Made Ground. In addition a small area of Middle Pleistocene Taplow Gravel was recognised in the most northerly part of the site, separated from the Holocene floodplain deposits by a well-marked bluff. The elevation OD of the upper boundary of units 1–4 and of the Taplow Gravel was entered into a database using RockWorks 2006 geological software. Contoured maps of surface height (Fig. 2) were generated for these units, and the thickness of the Holocene units and of the complete Holocene alluvial sequence was also modelled (Fig. 3).

The reliability of models generated using RockWorks depends fundamentally on the quality of the stratigraphic record, including the nature of the sediments and/or their post-depositional disturbance during previous stages of development on the site; and on the technical quality of the borehole records, put down at different times, by different companies, using different equipment, recorded using different descriptive terms, and subject to differing technical constraints in terms of recorded detail, including the exact levels of stratigraphic boundaries.

To explore the consistency of the borehole record, a comparison is made here between sequences recorded in the laboratory and those from geotechnical borehole logs. Table 1 compares each laboratory-based sequence with the sequence in the geotechnical borehole nearest to it, showing the level OD of the top of the peat; the level OD of the top of the gravel; and the thickness of the peat. Considering the many factors affecting the quality of the raw data from geotechnical boreholes, these comparative figures, with median values in all three cases substantially less than a metre and few outliers exceeding 1.0 m, indicate a degree of consistency that is probably acceptable for most practical purposes – for example, as a margin of caution to be exercised in groundwork near sensitive geoarchaeological horizons.

How effectively Rockworks portrays the relief features of stratigraphic contacts or the thickness of sediment bodies also depends very significantly on the number of data points per unit area and the extent to which these points are evenly distributed across the area of interest. In the present case, although borehole

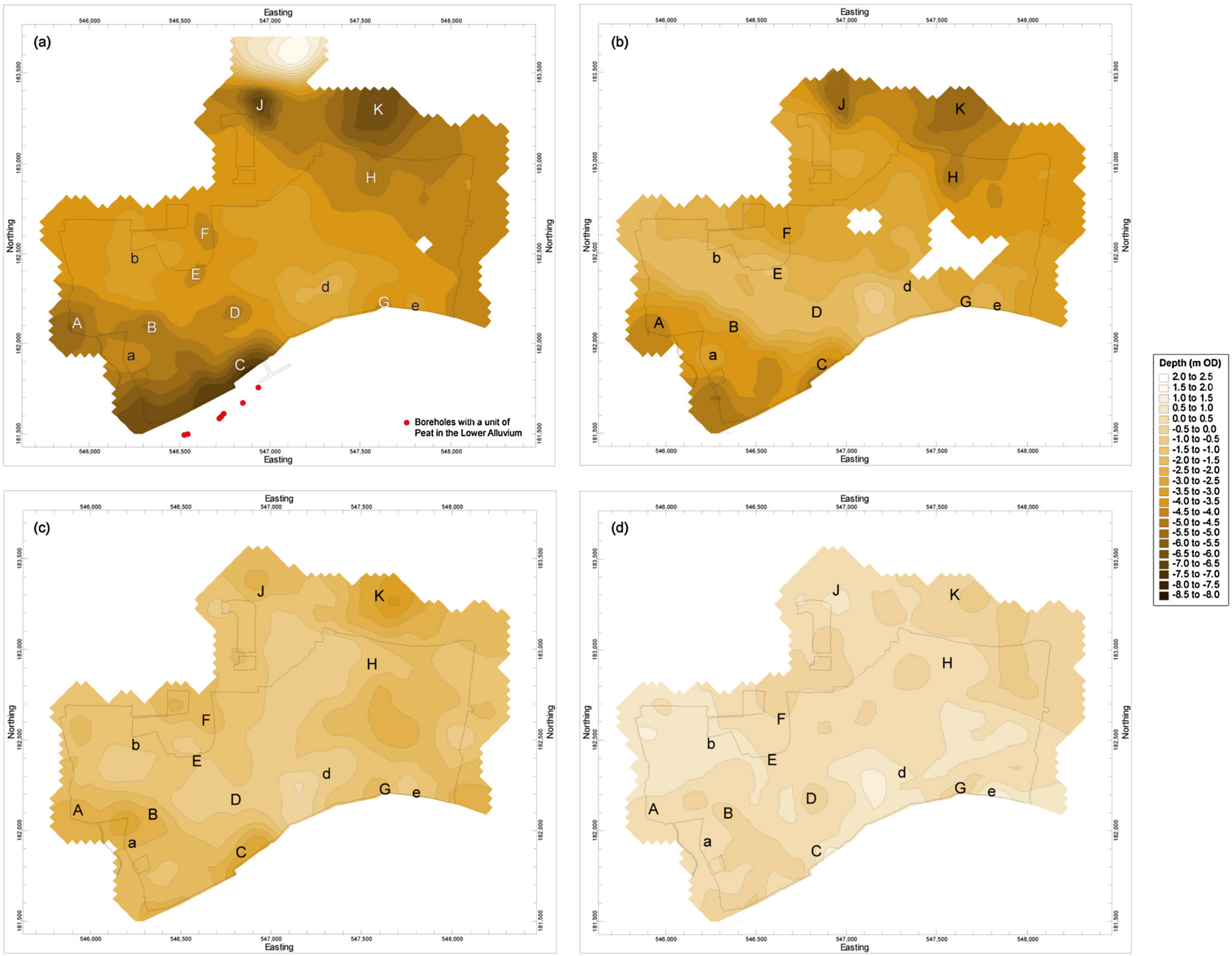

Fig. 2. Surface topographic maps (m OD) for (a) the Shepperton Gravel (including the location of major peaks and troughs in the Shepperton Gravel surface and of those boreholes with Peat in the Lower Alluvium, and); (b) the Lower Alluvium; (c) Peat, and (d) the Upper Alluvium.

data are lacking in 97 (35%) of the 100 m squares into which the site is divided, all these 'deficient' squares are in contact with a square in which a borehole is recorded.

The portrayal is also affected by the significance assigned to the point data (individual borehole records) in terms of the extent of the area around the point to which the data are deemed to apply. This can be predetermined for each data set, as a percentage of the total area of investigation. Obviously the larger the chosen percentage value the less reliable the overall portrayal. In the present case the value chosen for all the data sets was 5%. This is equivalent to an area of nearly 14 hectares or a circle around the data point with a radius of *c.* 210 m. This means that where a 100 m square lacks a borehole record, its stratigraphic characteristics will be mapped on the basis of data recorded in one or more of the immediately adjoining squares.

2.3. Sedimentary architecture

In the following paragraphs, the arrangement of the main stratigraphic units underlying the Barking site is described on the basis of the borehole evidence and the results of the deposit modelling exercise.

Table 1
Comparison of the geotechnical and geoarchaeologically described sedimentary sequences.

Geoarchaeological borehole	Geotechnical borehole	Differences (m)		
		Top of Peat	Peat thickness	Top of Gravel
H3	HJTS.BH88	0.29	0.15	0.26
H4	FES.FB07	0.20	n/d	0.24
H5	FES.FB07	1.21	n/d	0.39
H7	FES.2BBH12	0.16	0.06	0.35
FB1	NH.BH23A	0.36	0.25	0.83
FB2	NH.BH44	n/d	n/d	0.72
FB3	NH.BH36	n/d	n/d	0.33
Median values		0.25	0.08	0.64

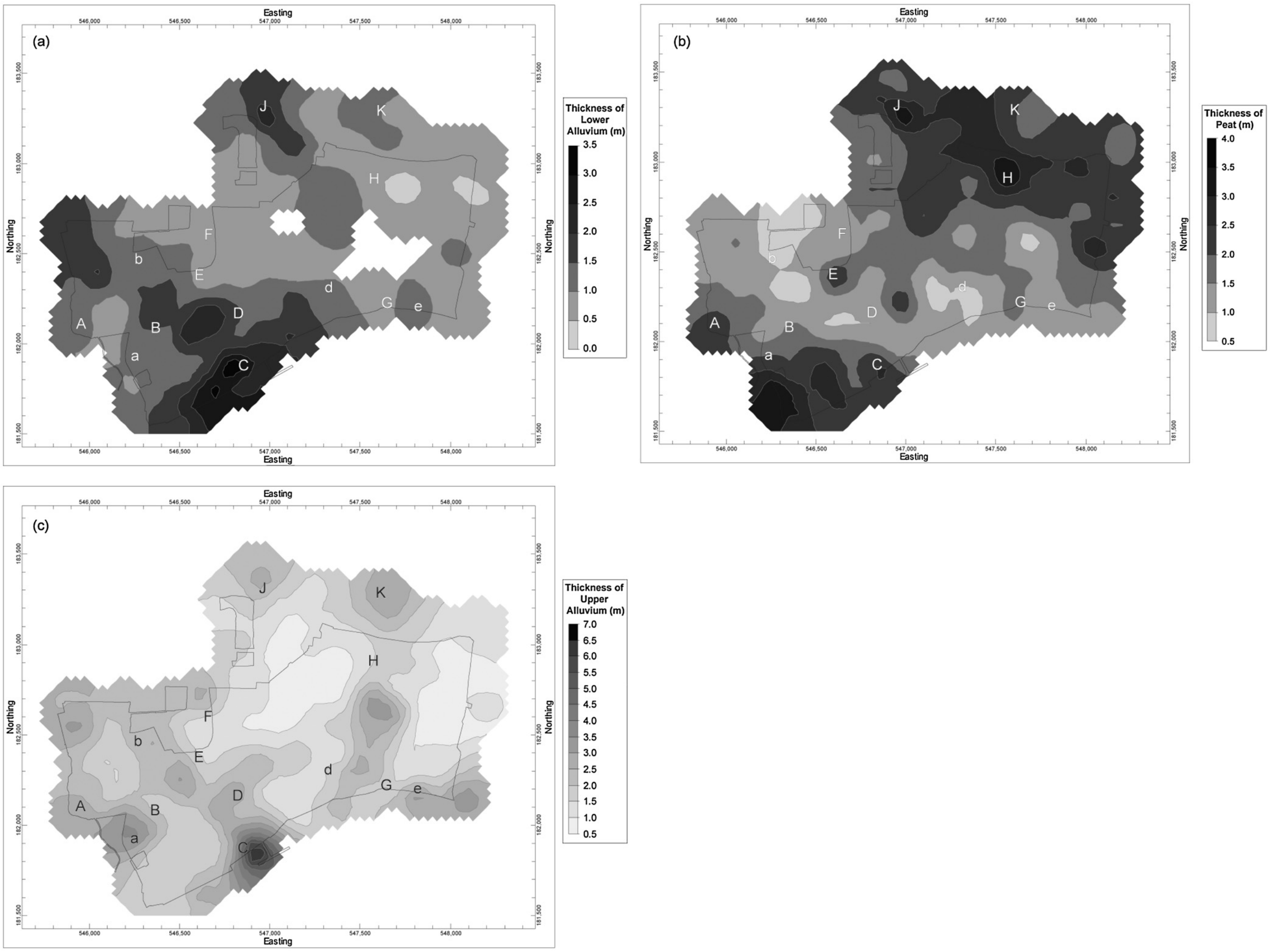

Fig. 3. Thickness (m) of: (a) the Lower Alluvium; (b) Peat, and (c) the Upper Alluvium.

2.3.1. *Taplow Gravel*

In the northern extremity of the site (Fig. 2) the surface of the Taplow Gravel lies between 0.75 m and 2.00 m OD and is separated from the general level of the nearby surface of the Shepperton Gravel by a bluff, rising some 5.0–6.0 m over a distance of *c.* 170 m and forming the northern edge of the Thames floodplain. The base of the Taplow Gravel here is between *c.* −0.8 and *c.* −1.6 m OD; thus, when the Late Devensian Shepperton Gravel was being deposited and in the Early Holocene, the lower part of the bluff would have exposed the easily eroded London Clay bedrock.

2.3.2. *Shepperton Gravel*

The base of the Holocene alluvial sequence is the uneven surface of the Shepperton Gravel (Fig. 2(a)). In the boreholes where this surface could be recognised, it is mainly at levels between −3.0 m and −5.0 m OD (59.9% of boreholes) where it has a gently undulating relief (mean: −4.58 m OD, σ: 4.55 m, n = 274). Small areas rise above −3.0 m OD (16.23% of boreholes) and a greater area lies below −5.0 m OD (23.08% of boreholes). Some of the more distinctive relief features on the surface of the Shepperton Gravel are identified in Fig. 2(a). Ten depressions are recognised (A–K), several of them apparently closed depressions (B, D, E F, H, J, K) and four relatively upstanding areas of gravel (a, b, d, e). Throughout the Holocene these features have had a persistent influence on sediment accumulation and this is discussed more fully in the following paragraphs. The surface of the gravel comes closest to the natural ground surface in a broad 'swell', generally above −4.0 m OD extending from WNW to ESE across the middle of the site, rising to its highest level, above −2.5 m OD, towards its eastern end. This gravel 'swell' is divided into three areas (b, d, e) of unequal size by shallow (*c.* 0.5 m), depressions (E, F, G) extending across it from north to south. To north and south of the gravel 'swell', and below −4.5 m OD the gravel surface falls away, to below −6.0 m OD near the Thames waterfront in the south (area C) and to similar levels close to the edge of the floodplain in the north (areas J and K). In the south, the low-lying area may represent the northern edge of a deeper pre-Holocene depression reflecting erosion associated with Late Devensian low sea levels. In the north near the edge of the floodplain the deep depressions in the gravel surface may represent scour holes formed in a major channel of the braided pre-Holocene Thames. Alternatively they may have been produced by water flowing off the higher ground to the north. There is some indication elsewhere in the Lower Thames Valley of similar depressions in the gravel surface underlying the edge of the floodplain (Stafford et al., 2012; Green et al., unpublished data).

2.3.3. *Lower Alluvium*

In the boreholes where the surface of the Lower Alluvium could be recorded, it is mainly at levels between −2.0 m and −4.5 m OD (78% of boreholes) (Fig. 2(b)). It has less relative relief than the surface of the underlying Shepperton Gravel (mean: −3.13 m OD, σ: 1.55 m, n = 200) with only small areas above −2.0 m OD or below −4.5 m OD (respectively 9.4% and 12.5% of boreholes). The Lower Alluvium comes closest to the ground surface over the broad 'swell' in the contours of the gravel, with its surface there between −1.5 m and −2.0 m OD, rising above −1.0 m OD at the eastern end of the 'swell' where the underlying gravel reaches its highest level. The surface of the Lower Alluvium declines on both sides of the 'swell', gently at first to the north and more steeply to the south, with a well-defined break of slope separating it from the low lying areas A, B and C. In both directions the surface of the Lower Alluvium reaches its lowest levels where the Shepperton Gravel is low-lying, by the waterfront of the present Thames in the south and by the floodplain edge in the north. In these areas, the surface of the Lower Alluvium is generally below −4.0 m OD and in the north west of the site (area J) below −5.0 m OD.

The relief on the surface of the Lower Alluvium (Fig. 2(b)) shows that it generally forms a layer resting conformably on the Shepperton Gravel. Thus many of the relief features recognised on the surface of the gravel retain subdued expression on the surface of the Lower Alluvium. In most places (80.3% of boreholes) the Lower Alluvium is less than 2.0 m thick (mean: 1.32 m, σ: 1.00 m, n = 184), being thinnest immediately to the north of the WNW-ESE 'swell' in the gravel surface, slightly thicker over the swell itself and thickest where the surface of the gravel is low-lying, particularly in low-lying areas C, D and J, but also infilling the smaller low-lying areas D, E, F and G which therefore lack expression on the surface of the Lower Alluvium (Fig. 3(a)). As a result, the WNW-ESE 'swell' is more clearly defined and more continuous on this surface than it was on the surface of the gravel. In 49 boreholes no Lower Alluvium was recorded overlying the Shepperton Gravel. These boreholes are mainly located either to the north of the 'swell' where the Lower Alluvium is also thinnest, or to the south where there is some indication of a greater frequency in a zone alongside the present course of the Thames.

2.3.4. Peat

The upper surface of the peat is mainly at levels between −0.5 m and −2.5 m OD (82% of boreholes). It has less relative relief than the surface of the underlying deposits (Lower Alluvium and Peat) with a mean elevation of −1.54 m OD (σ: 1.20 m, n = 248). It rises above −0.5 m OD in only two boreholes and most of the remaining boreholes record levels between −2.5 m and −4.0 m OD, with only six boreholes recording levels below −4.0 m OD. The influence of relief features on the surface of the Shepperton Gravel, as reflected in the surface of the Lower Alluvium, is still apparent in the contours of the peat surface. In particular the high points b, d and e, and the low-lying areas B, C, J and K are all recognisable. In general, the peat is thinnest (<1.0 m) over the broad WNW to ESE 'swell' where the Shepperton Gravel and the Lower Alluvium are at their highest levels; while the thickest peat accumulations occupy the principal depressions in the surface of the Lower Alluvium, by the Thames in the south and by the floodplain edge in the north. Thicknesses of up to 4.0 m of peat were recorded in areas B, C, H and J, with the result, in the case of area H, that it no longer has any expression in the contours of the peat surface. Overall the mean thickness of the peat is 1.94 m with 76.5% of the boreholes recording thicknesses of less than 2.5 m. In 40 of the boreholes the peat was absent altogether. Many of these boreholes are in the areas where the underlying Shepperton Gravel and Lower Alluvium rise to their highest levels, but there is some indication that the peat is locally absent in a zone adjoining the present course of the Thames.

2.3.5. Upper Alluvium

Where the peat is present, it is overlain almost everywhere by the silty and clayey Upper Alluvium. In recording the surface of the Upper Alluvium, i.e. the original natural surface of the floodplain, there is an element of uncertainty on account of the unknown extent to which the natural ground surface was modified prior to the emplacement of the Made Ground and the difficulty in some boreholes of distinguishing between the Made Ground and the alluvium. However, in the majority of boreholes (83%), the upper surface of the Upper Alluvium is recorded at levels between 1.5 m and −1.0 m OD with a mean elevation of 0.03 m OD (n = 323). There is slightly more variability (σ: 1.38 m) than is recorded on the surface of the underlying peat (σ: 1.20 m), which may be a reflection of the uncertainties surrounding the identification of the original natural ground surface. In most places (85% of boreholes) the Upper Alluvium is less than 2.5 m in thickness (mean 1.59 m, σ: 0.87 m, n = 252) with only nine boreholes recording thicknesses greater than 3.5 m. Comparison between the thickness of the Upper Alluvium and the contours of the underlying surface of the peat shows very clearly that the Upper Alluvium is almost invariably thicker where the peat surface is low-lying, with the result that across most of the site, the surface of the Upper Alluvium displays little relief and the influence of inequalities in the surface of the Shepperton Gravel is hardly discernible.

3. Biostratigraphy and geochronology

3.1. Methods

Detailed lithostratigraphic and geochronological investigations were undertaken on four of the collected sequences from Barking Riverside (H4, RG10, FB1 & FB4) and three from Renwick Road (QBH1, QBH4 & QBH5). Each core sample was cleaned, the lithostratigraphic sequence was described (Troels-Smith, 1955), and the heights above mean sea level noted (British Ordnance Datum – m OD). The organic matter content was determined using the loss-on-ignition method (Bengtsson and Enell, 1986). Terrestrial plant remains (identified seeds or wood) were extracted for radiocarbon assay from points of high organic matter content towards the top and base of the peat in each borehole to establish a chronology for the period of peat formation. The radiocarbon determinations were calibrated using the maximum intercept method (Stuiver and Reimer, 1986), OxCal v4.2 (Bronk Ramsey, 1995, 2001), and the internationally agreed dataset for terrestrial samples from the northern hemisphere (Reimer et al., 2009). The full age range (rounded to 10 years) is quoted as 'cal BP' (Table 2; Fig. 4).

Detailed biostratigraphic investigations (pollen, plant macrofossils and diatoms) were undertaken on six sequences (H4, RG10, FB1, FB4, QBH1 & QBH5). However, in this paper, a summary of the results is only provided from H4 (Fig. 5), FB4 (Fig. 6) and QBH5 (Fig. 7). These were selected as they are located towards the western, south-eastern and northern boundaries of the study area.

Pollen grains and spores were extracted following standard procedures (Branch et al., 2005), and identified using type collections and the keys and photographs in Moore et al. (1991) and Reille (1992). Plant nomenclature follows the Flora Europaea as summarised in Stace (2005). In all, 300 pollen grains (excluding aquatics and spores) were recorded for each sample. The results are expressed as a percentage of total land pollen (trees, shrubs and herbs). Variations in percentage pollen values have been used divide the pollen assemblage into local pollen assemblage zones (LPAZ's) where appropriate.

Plant macrofossils (seeds, fruit bodies and wood) were extracted from small sub-samples (often < 0.1 l), by dispersal in hot water, and sieving through 1 mm and 300 μm mesh sizes. All extracted waterlogged seeds, and 10 randomly selected fragments of wood were identified from each sample using standard techniques (Gale and Cutler, 2000). Identifications of the remains, were been made using modern comparative material and reference atlases (Cappers et al., 2006; Hather, 2000; Schweingruber, 1990; Schoch et al., 2004). Nomenclature used follows Stace (2005).

Table 2
Radiocarbon dates from Barking Riverside and Renwick Road.

Laboratory code/ Method	Borehole number	Depth (m OD)	Material	Uncalibrated ^{14}C date (BP)	Calibrated ^{14}C date (BP) 95.4%	δ^{13}C (‰)
Beta-287634 AMS	<H4>	−1.30 to −1.40	*Fraxinus* twig	3270 ± 40	3580–3400	−28.0
Beta-287635 AMS	<H4>	−2.00 to −2.10	*Alnus glutinosa* wood	3840 ± 40	4410–4100	−28.1
Beta-287636 AMS	<H4>	−2.90 to −3.00	*Alnus glutinosa* wood	4570 ± 40	5440–5060	−28.7
Beta-287637 AMS	<H4>	−3.50 to −3.60	*Alnus glutinosa* wood	5330 + 40	6270–5990	−30.2
Beta-287638 AMS	<RG10>	−1.89 to −1.93	*Alnus glutinosa* wood	3700 ± 40	4150–3920	−28.3
Beta-287639 AMS	<RG10>	−2.27 to −2.37	*Alnus glutinosa* wood	4570 ± 40	5440–5060	−27.0
Beta-287630 AMS	<FB1>	−1.14 to −1.24	*Alnus glutinosa* wood	3150 ± 40	3450–3280	−29.2
Beta-287631 AMS	<FB1>	−1.90 to −1.98	*Alnus glutinosa* wood	3810 ± 40	4390–4090	−29.3
Beta-287632 AMS	<FB4>	−1.28 to −1.33	*Alnus glutinosa* wood	3160 ± 40	3450–3330	−27.6
Beta-287633 AMS	<FB4>	−1.91 to −1.93	*Alnus glutinosa* wood	3800 ± 40	4340–4080	−29.5
Beta-324680 AMS	<QBH1>	−1.80 to −1.90	Unidentified twig wood	3290 ± 30	3580–3450	−27.1
Beta-324681 AMS	<QBH1>	−3.00 to −3.10	*Alnus glutinosa* catkins	5250 ± 40	6180–5920	−26.4
Beta-324682 AMS	<QBH4>	−2.45 to −2.50	*Alnus glutinosa* catkins	2960 ± 30	3240–3000	−27.1
Beta-324683 AMS	<QBH4>	−2.80 to −2.85	Unidentified twig wood	4980 ± 40	5880–5610	−27.6
Beta-324684 AMS	<QBH5>	−1.45 to −1.50	Unidentified twig wood	3350 ± 30	3680–3480	−27.7
Beta-324685 AMS	<QBH5>	−2.65 to −2.70	Unidentified twig wood	4880 ± 30	5660–5590	−27.0

Diatom preparation from the Lower and Upper Alluvium (Fig. 2) followed standard techniques with two sets of slides prepared to confirm the absence of diatoms from a number of samples (Battarbee et al., 2001). Several diatom floras and taxonomic publications were consulted to assist with diatom identification, including Hendey (1964). Diatom species' salinity preferences were classified using the halobian groups of Hustedt (1953, 1957: 199).

3.2. Palaeoenvironmental interpretation

A summary reconstruction of the palaeoenvironmental conditions during the accumulation of the Holocene sequence is provided here on the basis of the results of the biostratigraphic and geochronological investigations.

The Lower Thames Valley may be classified as a coastal wetland environment (Waller, 1993, 1998) and as in other coastal wetlands in southern England, such as the East Anglian Fens (e.g. Waller, 1994a) and Somerset Levels (Bell et al., 2000), this environment supported a thick sequence of peat deposits dated to the Middle Holocene. The timing of the onset and cessation of this peat has generally been related to the behaviour of sea level (e.g. Devoy, 1979; Long et al., 2000; Sidell, 2003) and in the Lower Thames Valley, research by Sidell (2003) indicates that widespread peat initiation occurred between *c.* 6800 and 5800 cal BP in response to a reduction in the rate of relative sea level rise (RSL) (from 2.6 mm/year to 0.8 mm/year) that commenced around 8000 cal BP. Conversely, peat ceased to form between *c.*3500 and 2500 cal BP following an increase in the rate of RSL rise to 1.9 mm/year. The following account deals mainly with the record preserved in the Peat, including consideration of the factors associated with the onset and cessation of peat formation. Evidence relating to conditions associated with the deposition of the Lower Alluvium and the Upper Alluvium is much more limited at the Barking Riverside and Renwick Road sites, but the biostratigraphic records are consistent with the view that variations in RSL were a significant factor influencing the history of Holocene alluvial deposition.

3.2.1. Lower Alluvium

In the Lower Alluvium, prior to the onset of peat formation, polyhalobous and mesohalobous diatoms, indicative of marine or estuarine conditions are recorded in borehole H4 (Fig. 5). Elevated values of *Chenopodium* type, *Pinus* and *Pteridium aquilinum* in LPAZ H4-1 are also indicative of alluvial and estuarine conditions, with *Chenopodium* type possibly representing the growth of salt marsh taxa, whilst *Pinus* pollen and *Pteridium aquilinum* spores are often over-represented in water-lain sediments due to their ability to float long distances (Campbell, 1999). Unfortunately, there is insufficient information from the Renwick Road boreholes to test whether the Lower Alluvium in northern depression J, also accumulated under estuarine conditions (QBH5; Fig. 7). However, it is of interest that high microcharcoal values are recorded there at the very top of the Lower Alluvium, effectively on the alluvial surface, immediately beneath the overlying peat (QBH5; Fig. 7). These values are interpreted as representing *in situ* or nearby burning, and thus the development of a more terrestrial surface prior to the onset of peat formation (*c.* 5660–5590 cal BP). Whether the microcharcoal is of anthropogenic or natural origin is unknown. Whilst palaeoecological or archaeological evidence for human activity have not been recorded at Barking Riverside or Renwick Road during this period, Neolithic (*c.* 6300–4200 cal BP) pottery and burnt flints have been recorded along the route of the A13, at Movers Lane (Stafford et al., 2012; Fig. 1), and a concentration of pottery, burnt flint and carbonised grain has been recorded further west along the A13 at Woolwich Manor Way (Stafford et al., 2012) dated to 5890–5320 cal BP. Both of these sites are located on the interface between the floodplain edge and dryland.

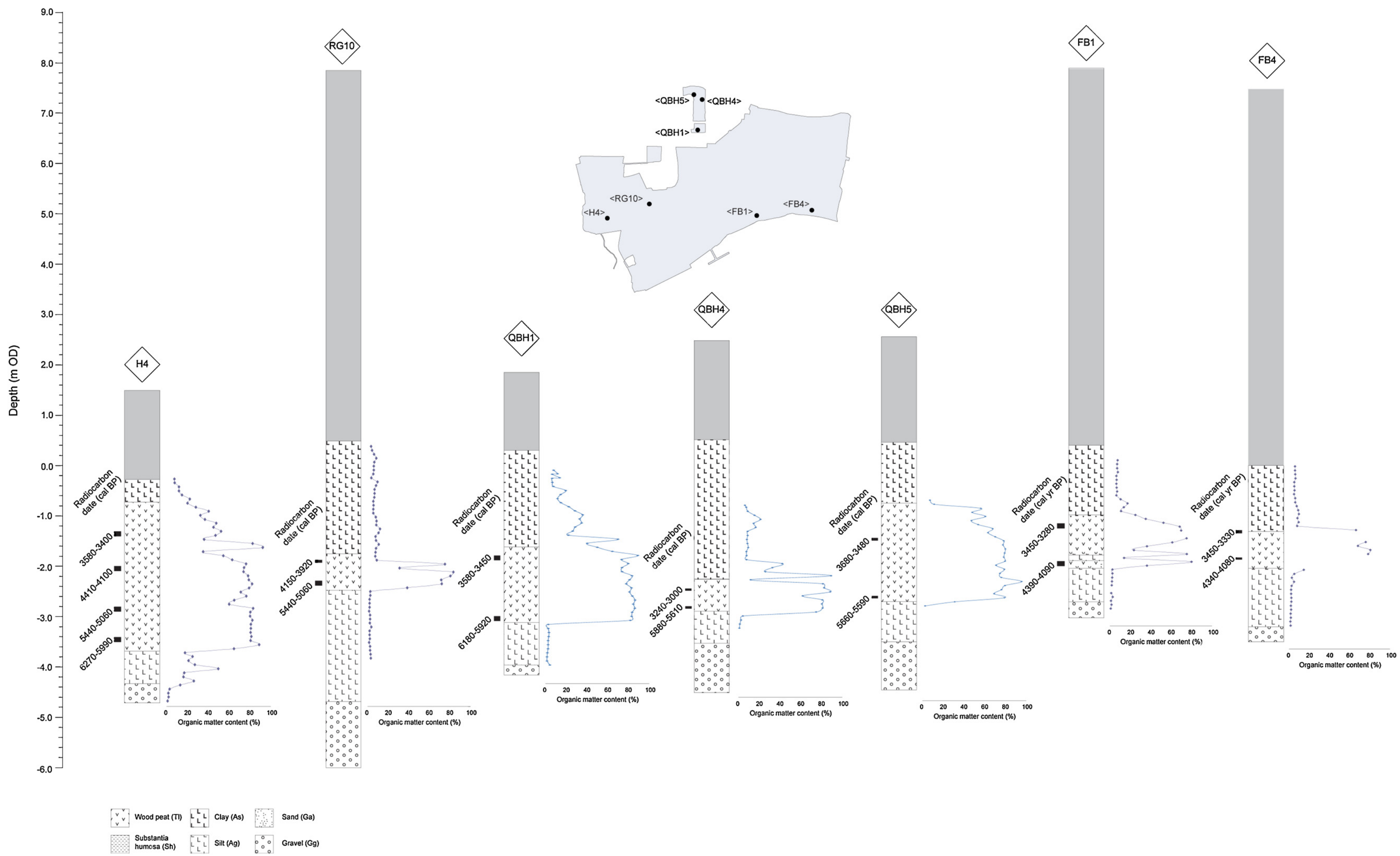

Fig. 4. Radiocarbon-dated lithostratigraphic and organic matter sequences from Barking Riverside and Renwick Road.

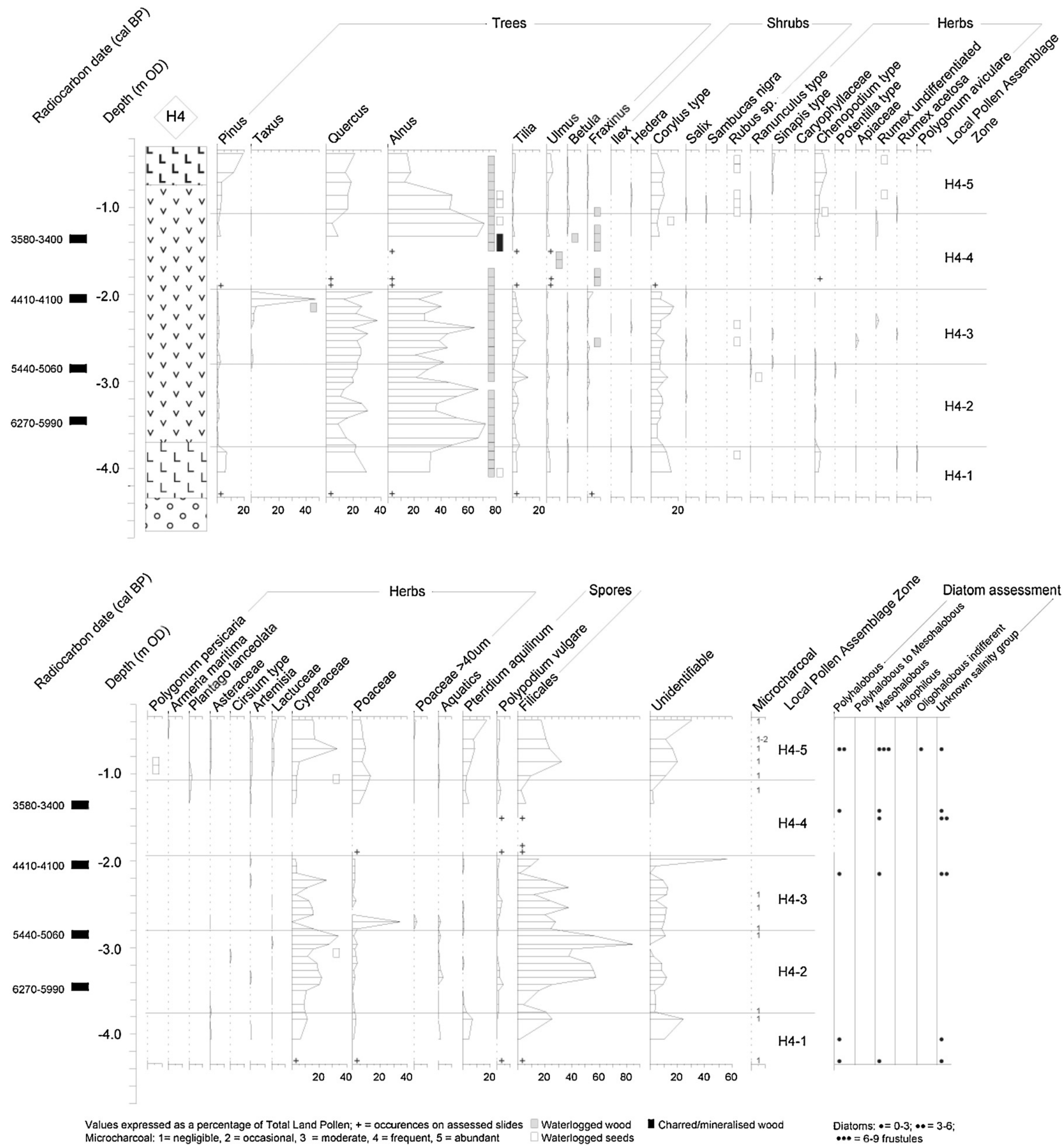

Fig. 5. Summary biostratigraphic diagram from borehole H4 incorporating the results of the pollen, waterlogged plant macrofossil (seeds and wood) and diatom investigations.

3.2.2. Peat

The results of the radiocarbon dating show that the peat accumulated between approximately 6200 and 3400 cal BP, which is equivalent in age to Devoy's (1979) Tilbury III peat. The results also demonstrate a strong relationship between peat depth and the date of its formation (Fig. 4). Thus, below −3.0 m OD in boreholes H4 and QBH1 peat initiation commenced before 6000 cal BP; between approximately −3.0 and −2.5 m OD in boreholes H4, RG10, QBH4 and QBH5 peat was forming or began to form between 6000 and 5500 cal BP; at *c.* −2.0 m OD in boreholes H4, RG10, FB1, FB4 peat was forming, began to form or ceased to form between 4500 and 4000 cal BP; and between approximately −1.8 and −1.2 m OD in boreholes H4, QBH1, QBH5, FB1 and FB4 peat stopped forming between 3600 and 3300 cal BP. It appears therefore that the date of peat initiation is closely related to topographic variations in the underlying surface of the Lower Alluvium (as described above), with peat formation commencing earlier where the surface of the Lower Alluvium was lower and later where it was higher. Unsurprisingly, there are some departures from this general rule, for example, peat initiation commenced earlier in borehole RG10 than might be predicted from the level of the base of the peat; while in borehole QBH4, peat formation appears to have terminated at a lower elevation than might be predicted from the level of the top of the peat. However evidence such as this, apparently indicating an early end to peat formation, may reflect truncation of the peat and the deposition of older material, either by natural erosional processes or by later human activity.

Throughout the greater part of all the peat sequences, organic matter determinations of approximately 80% were recorded, indicating that for most of the time the peat surface was relatively dry. However, the 20% mineral fraction was most likely derived from episodic flooding, probably on a seasonal basis, while lower organic matter values, down to 60% (e.g. −2.80 m to −2.40 m OD in H4)

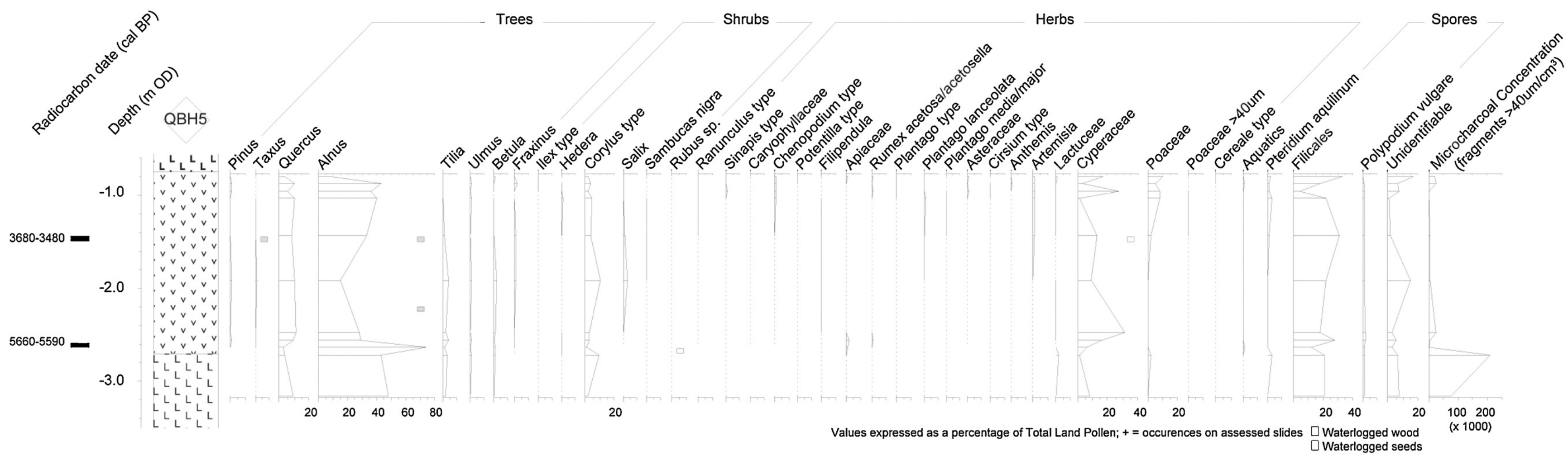

Fig. 6. Summary biostratigraphic diagram from borehole QBH5 incorporating the results of the pollen, waterlogged plant macrofossil (seeds and wood) and diatom investigations.

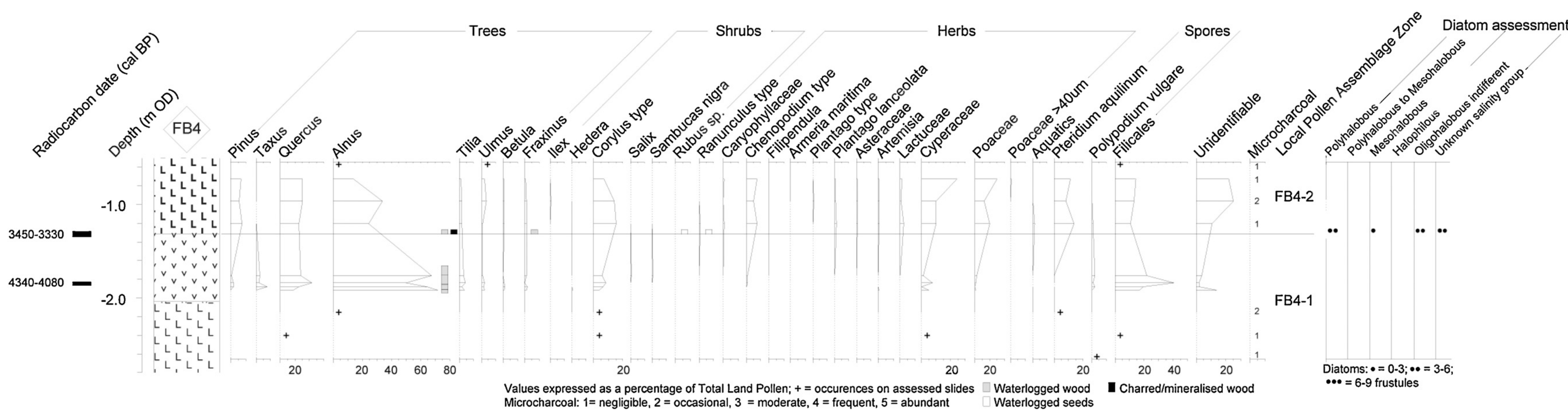

Fig. 7. Summary biostratigraphic diagram from borehole FB4 incorporating the results of the pollen, waterlogged plant macrofossil (seeds and wood) and diatom investigations.

suggest inundation of greater magnitude and/or duration. However identifiable flooding events were not contemporaneous between boreholes, which suggests that they were unrelated to regional changes in hydrological conditions, but are more to likely reflect the influence of local topographic factors. This is entirely consistent with the relief of the surface on which the peat was accumulating which appears to have been characterised by a variety of effectively separate and in some cases closed depressions.

All of the biostratigraphic records (Figs. 5–7) indicate that the peat surface was colonised by dense fen carr woodland dominated by *Alnus glutinosa*, with *Salix* and *Rubus*. The ground flora comprised a mixture of herbs and ferns including Poaceae, Cyperaceae, *Filicales, Polypodium vulgare Ranunculus*, *Rumex*, *Potentilla*, Apiaceae and *Artemisia*. The presence of aquatic taxa such as *Sparganium* and *Typha latifolia* indicate that areas of still or slowly moving water existed on the peat surface. Other trees and shrubs such as *Betula*, *Fraxinus* and *Corylus* may have formed a lesser component of the fen carr woodland, but were equally likely to have grown on the dryland forming part of the mixed deciduous woodland dominated by *Tilia* and *Quercus* with *Ulmus*.

There is a decline in *Ulmus* values at the interface between the Lower Alluvium and Peat in borehole H4 sometime prior to 6270–5990 cal BP. Whilst a weak signal, the decline is of note because it correlates with the well-documented middle Holocene elm decline which is recorded across the British Isles between 6347 and 5281 cal BP (Parker et al., 2002). Numerous causal hypotheses have been proposed for the elm decline including: (1) human interference (e.g. Scaife, 1988); (2) disease (e.g. Girling and Grieg, 1985; Clark and Edwards, 2004); (3) climatic change (e.g. Parker et al., 2002); (4) soil deterioration and paludification (Batchelor et al., in press-a); (5) competition (e.g. Parker et al., 2002), and (6) a combination of causal factors (e.g. Parker et al., 2002; Lamb and Thompson, 2005). In borehole H4, the contemporaneous transition towards peat formation is strongly suggestive of paludification and the expansion of floodplain woodland. This process would have negatively impacted upon elm populations, by either: (1) leading to a loss of habitat and the introduction of competitive relationships close to the dryland edge, and/or (2) causing a reduction in pollen recruitment from the dryland (e.g. Waller, 1994b; Grant et al., 2011; Batchelor et al., in press-a). A recently proposed classification system identifying the different cause(s) of the decline at individual sites indicated that paludification was one of the most common influences in the Lower Thames Valley (Batchelor et al., in press-a). However, it is not anticipated that this factor caused the long-term and widespread reduction of elm, but that evidence of other factors is masked as a consequence of the site's proximity to the dryland edge (Batchelor et al., in press-a).

From approximately 5000–4000 cal BP, *Taxus* expanded to become an important component of the fen carr woodland. This colonisation is recorded in all of the biostratigraphic records (Figs. 5–7), but is most evident in borehole H4, LPAZ H3, where it expanded to become co-dominant with *Alnus* (Fig. 5). The growth of *Taxus* on fen peat from around 5000 cal BP is now a well-recognised feature of pollen diagrams from the Lower Thames Valley (e.g. Seel, 2001; Batchelor, 2009b; Branch et al., 2012), and other coastal wetland environments such as the East Anglian Fens (e.g. Godwin, 1975), Somerset Levels (e.g. Beckett and Hibbert, 1979) and Belgian Coastal Plains (Deforce and Bastiaens, 2007). There is no modern British analogue for this community. The possible reasons for its colonisation and decline on fen peat are discussed in detail elsewhere (Batchelor, 2009b; Branch et al., 2012), but drier peat surface conditions seem a likely prerequisite. At around 4000 cal BP, following the decline of *Taxus*, the growth of *Ulmus* on the peat surface is indicated by waterlogged wood identifications in boreholes H4 and FB1 (Figs. 5 and 6). These occurrences add to a growing number of records from the Lower Thames Valley that indicate the growth of *Ulmus* on the peat surface around this time (e.g. Seel, 2001; Batchelor et al., 2009). Combined, the colonisation of *Taxus* and *Ulmus* is suggestive of the development of a more mature fen woodland habitat in response, to drier, more 'terrestrial' peat surface conditions from 5000 cal BP.

3.2.3. Peat-Upper Alluvium transition

The results of the radiocarbon dating indicate that the transition from the peat to the Upper Alluvium took place from 4000 to 3500 cal BP onwards. There is some suggestion that the rate at which this transition occurred was variable: in boreholes H4, QBH1, QBH5 and FB4, the gradual decline of organic matter values indicates a gradual change of environmental conditions, whilst in RG10 and QBH4 the decline was abrupt, suggesting a rapid change in conditions, or more likely, erosion of the peat (as already suggested above as a possible explanation for the low level of the top of the peat in borehole QBH4) (Fig. 4). However, dating the upper part of late Holocene coastal wetland peats is problematic due to the potential for reduced peat accumulation rates, erosion, reworking and compaction, as demonstrated by Waller et al. (2006). Thus, the precise timing of the transition from peat formation to deposition of the Upper Alluvium should be regarded with some caution.

Around the time of this transition in the biostratigraphic record, the occurrence of polyhalobous and mesohalobous diatom taxa in boreholes H4, RG10 and FB4, indicates the dominance of marine/brackish conditions, and thus an increase in the rate of RSL might be inferred (Figs. 5 and 6). The pollen-stratigraphic and plant macrofossil records indicate the decline of *Alnus* fen carr woodland and growth of sedge fen/reed swamp type communities in response to this environmental change. In addition to the dominance of Cyperaceae and Poaceae in these communities, the increased occurrence of *Chenopodium*, Asteraceae and *Armeria maritima* indicate the growth of saltmarsh plants. This period of environmental change is also marked by the relative decline of *Tilia* and *Quercus* pollen percentage values, representing the reduction of dryland woodland. The occurrence of an array of herbaceous taxa including Poaceae >40 μm (which might include cereal pollen), *Plantago lanceolata* and an increase in charcoal and microcharcoal concentrations suggest that Bronze Age land clearance for settlement and/or agricultural purposes may be have been the cause of this decline. This interpretation is reinforced by an increase in Bronze Age archaeological remains from several nearby sites indicative of increased exploitation. The most local of these sites are Hays Storage, where a sand and gravel causeway was recorded on the peat surface (Divers, 1996), and at Movers Lane where various features have been recorded including trackways, a middle Bronze Age burnt mound, cremation and ditches (Stafford et al., 2012) (Fig. 1).

The decrease of the woodland on the peat surface and on the dryland is therefore approximately contemporaneous, suggesting a link between the two environments and the possible causes. It seems probable that regular estuarine inundation would have caused paludification and reduced the area of dryland woodland (e.g. Waller, 1994b; Grant et al., 2011), with wetter conditions and flooding also leading to the abandonment of the floodplain by Bronze Age people, and the concentration of anthropogenic activity on the neighbouring dryland edge. It also seems likely that land clearance altered the depositional environment of the floodplain, with soil erosion providing an increased supply of sediment and increased run-off affecting the frequency and magnitude of floods (e.g. Burrin and Scaife, 1984; Scaife and Burrin, 1985; Brown, 1997). However, the precise temporal and spatial relationships between the rate of RSL rise, soil deterioration, human activity and vegetation change remain very difficult to measure as Waller and Grant (2012) have recently emphasised.

4. Discussion

4.1. The deposit models

In using the results of the deposit modelling to develop an understanding of Holocene landscape change on the valley floor of the Thames in the Barking area, it is very important to recognise what these models can and cannot show. Perhaps the most important consideration is the dimensions of the landforms that the models can represent. For most of the cartographic reconstructions, most points on the maps lie within the area of influence of at least one borehole. However, although there are as many as six boreholes in some 100 m squares, in large parts of the site, borehole spacing is no better than one borehole per 100 m square. This means that landforms with a lateral extent of less than 100 m will be difficult or impossible to detect. In addition, due to the limitations of the borehole record, discussed and evaluated above, reliable resolution of height differences of less than one metre are unlikely to be achieved. As a result of these various constraints, although the deposit models provide a robust representation of the large-scale landforms, they are not sufficiently refined to show details of the drainage networks, such as minor distributaries, abandoned channel remnants and tidal creeks, associated with the deposition of the alluvial sediments described below. Another important consideration is the extent to which the modelled surfaces are diachronous in origin. The models represent the spatial arrangement of the transition from one depositional environment to another. They are not however 'time horizons'. Diachroneity is undoubtedly present and may arise from one or both of two situations. On the one hand the formative processes responsible for the relief of the underlying unit are unlikely to become inoperative at the same time everywhere on the surface of that unit; and on the other hand the accumulation of the overlying unit is unlikely to commence simultaneously across the whole surface of the underlying unit. In the following paragraphs, where the evidence is reasonably clear, the presence of diachronous relationships is noted. It has to be recognised however that the detailed spatial pattern of such relationships is likely to be complex. A thorough examination of that complexity lies outside the scope of the present investigation.

4.2. Landscape evolution (Fig. 8; Table 3)

4.2.1. Shepperton Gravel

In the Lower Thames Valley, the Shepperton Gravel is the product of aggradation in response to rising relative sea level in the Late Devensian. At Barking the gravel rests on an uneven surface of Palaeogene sediment at levels between *c.* −16.7 m OD and *c.* −2.8 m OD. When aggradation of gravel ceased at the beginning of the Holocene, relative relief on the gravel surface was about 5 m with a low-lying area in the south near the modern waterfront and another in the north near the bluff marking the edge of the Late Devensian and Holocene alluvial valley floor. Between these two low-lying areas the surface of the gravel rises to a higher level, forming a broad, elongated but discontinuous 'swell' aligned approximately WNW-ESE.

The form and scale of these topographic features are consistent with their interpretation as large-scale elements of a braided or wandering river system (Miall, 1996). The low-lying areas appear to represent the level of the main active channels. Adopting a hierarchical classification of these topographic features (Miall, 1996), with the valley floor of the River Thames forming the first-order channel, these channels can be regarded as second order features. In the northern channel, deep enclosed hollows are present (Areas J and K) and another enclosed hollow may be present in the southern channel (Area B). Similar features have been described elsewhere on the basis of both flume and field evidence (Mosley, 1976; Best, 1987). They appear to be preferentially located close to channel junctions or where flow is deflected against the channel bank. In the present case the confluence of the River Roding with the Thames, just upstream from the Barking site may have created suitable conditions for their formation.

The more elevated surface between the two channels probably represents an area that was inundated only during flood stages. The overall dimensions of this more elevated surface, about 500 m wide and over a kilometre in length, suggest that, within the context of the Lower Thames Valley, it can be regarded as a first order bar. Following practice elsewhere in the Thames valley, it is proposed that this feature be termed the Barking Eyot. As is often the case in braided or wandering rivers, minor (third order) channels, represented here by Areas D, E, F and G, cut across this bar and divide it into lower (second) order elements represented by Areas b, d and e. Another topographic feature characteristic of the braided or wandering river environment is present on the south side of the bar where there is a well-defined step-like linear break of slope about 1–1.5 m high, almost certainly a cut-bank marking the edge of the bar and representing evidence of undercutting due to the active migration of the neighbouring channel.

The broad pattern of relief described here on the surface of the Shepperton Gravel is strikingly similar to the pattern described by Corcoran et al. (2011) just downstream from the confluence of the River Lea with the Thames. Here, as at Barking, a substantial buried channel is present close to the northern edge of the floodplain and separated from a similar channel further south by an extensive sand-covered bar. Corcoran et al. (2011) suggest that the more northerly channel may have been occupied by a distributary of the River Lea, and it seems equally possible that at Barking the northern channel was formed by the River Roding.

4.2.2. Lower Alluvium

The sandy Lower Alluvium as recorded in this account almost certainly comprises sediment representing two distinct phases of deposition. To this extent at least, the modelled surface of the Lower Alluvium is diachronous. The thickening of the Lower Alluvium over the more elevated gravel surface of the Barking Eyot is consistent with patterns of sedimentation in braided or wandering river environments, where sandy deposits typically mantle those areas (bars) that rise above the level of the main active channels and experience sediment accretion only during flood events. At Barking such sandy deposits probably formed in association with the aggradation of the Shepperton Gravel and are therefore of Late Devensian age. Many of the sandy sub-units in the Lower Alluvium, in which organic remains are rare or absent may belong in this depositional stage. However in many boreholes organic remains are well represented in the Lower Alluvium, including Mollusca, wood and other plant material. Where this is the case, the sediment is almost certainly of Early Holocene age. This is more clearly indicated in several boreholes located in the channel to the south of the Barking Eyot where peat is present in or beneath the Lower Alluvium resting on surfaces between −8.67 m OD and −5.9 m OD. It was not possible during the present investigation to date these peats, but elsewhere in the Lower Thames Valley (Young, 2012; Batchelor et al., in press-b) peat at similar levels has been dated to intervals between 10,740 cal BP and 6750 cal BP. Conditions favouring uninterrupted peat formation evidently did not persist in this part of the Barking site in the Early Holocene, due no doubt to the continuing rise of relative sea level and associated influxes of predominantly minerogenic sediment. Peat at this level has sometimes been regarded as equivalent to the Tilbury II peat of Devoy (1979), but see below for a fuller discussion of Early Holocene peat formation in the Lower Thames Valley.

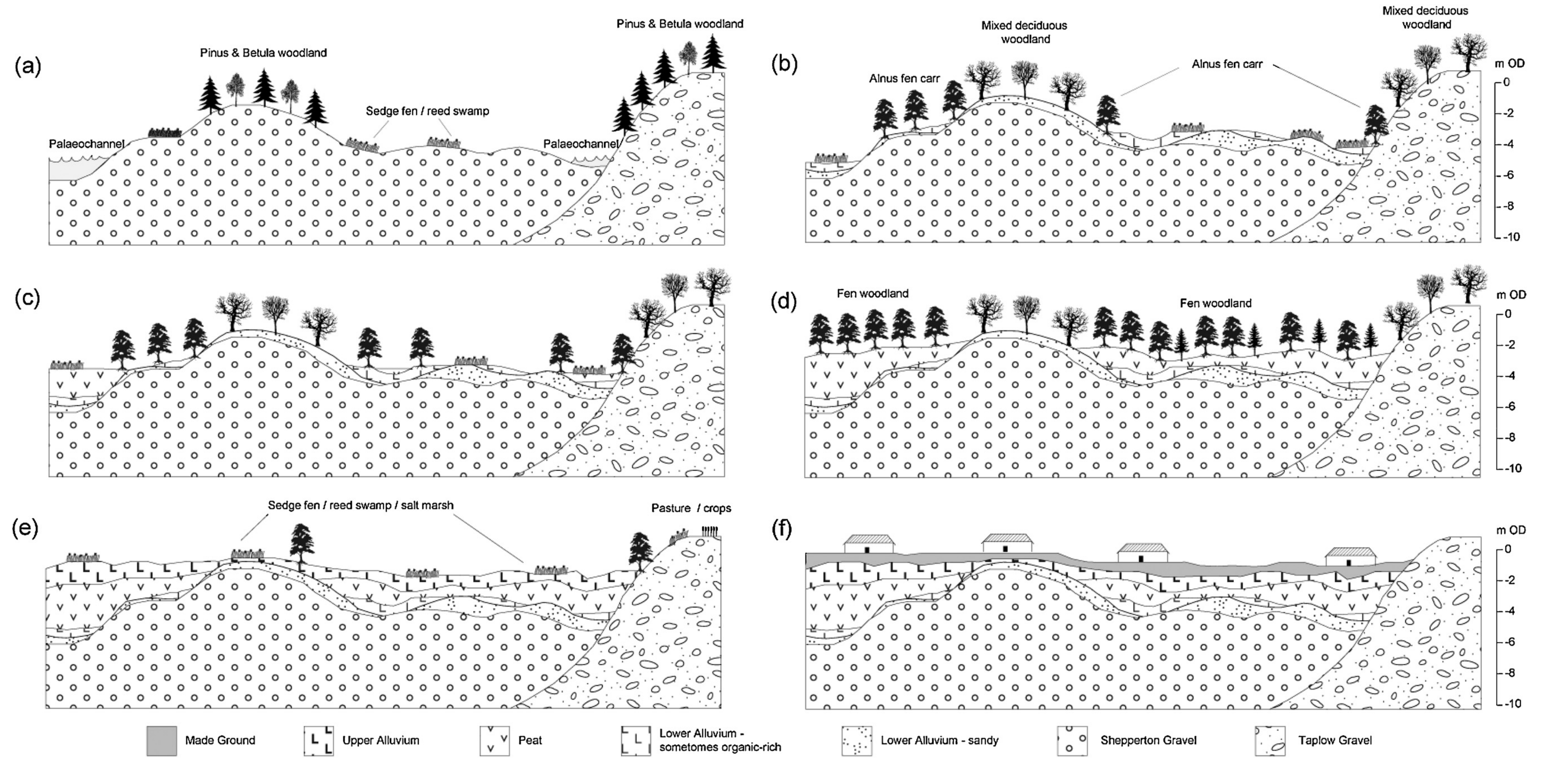

Fig. 8. Barking landscape model: (a) the basal topography of the Late Devensian/early Holocene Shepperton Gravel surface. *Pinus* and *Betula* woodland grew on the Taplow Gravel terrace and Shepperton Gravel eyots, whilst non-inundated areas of the floodplain supported sedge fen/reed swamp type communities; (b) the topography of the landscape following deposition of the sandy and sometimes organic-rich Lower Alluvium (*ca*. 10,000 to 6000 cal BP). *Pinus* and *Betula* woodland was replaced by mixed-deciduous woodland dominated by *Quercus* and *Tilia* with *Ulmus*. Sedge fen/reed swamp type communities occupied non-inundated areas of the floodplain whilst *Alnus* fen carr grew in drier areas on the floodplain margin. (c) Peat formation commenced in topographic depressions on the floodplain from *ca*. 6000 cal BP and was colonised by *Alnus* fen carr woodland. *Ulmus* underwent a decline on the dryland; (d) Peat expanded upwards and outwards across the floodplain and the fen carr woodland matured; (e) Inundation of the Peat surface led to the reduction of fen carr woodland and growth of sedge fen/reed swamp/saltmarsh communities. Late prehistoric activity led to wide-scale woodland clearance on the dryland; (f) Made-up ground to the present-day surface.

Table 3
Summary of environments represented in the late Devensian and Holocene sediments at Barking.

Lithostratigraphy (*mean surface level and mean thickness*)	Lithology	Salinity	Floodplain landscape	Vegetation	Cultural period	Age
Upper Alluvium *surface level: 0.03 m OD* *thickness: 1.59 m*	Massive sandy silts	Brackish	Large meandering brackish river and estuarine floodplain	*Floodplain* – sedge fen/reed swamp and salt marsh Dryland – Continued reduction of woodland cover	Post late Bronze Age	From *ca.* 4000 to 3500 cal BP
Peat *surface level: −1.54 m OD* *thickness: 1.94 m*	Wood peat	Freshwater	Large meandering freshwater river floodplain;	*Floodplain* – *Alnus*-dominated fen carr woodland, initially on peat in depressions, subsequently spreading progressively and widely across the floodplain. *Taxus* colonises the peat surface between *ca.* 5000 and 4000 cal BP, and *Ulmus* from 4000 cal BP. Fen carr woodland declines towards top of peat. *Dryland* – early Neolithic *Ulmus* decline during late stages of Lower Alluvium/early stages of Peat formation. Reduction in woodland cover from *ca.* 4000 cal BP	Bronze Age, Neolithic, late Mesolithic	Peat formation ceased *ca.* 3600–3300 cal BP Peat formation commenced *ca.* 6000 cal BP
Lower Alluvium *surface level: −3.13 m OD* *thickness: 1.32 m*						
Lower Alluvium – sometimes organic-rich	Bedded and massive sands and silts	Brackish	Large meandering brackish river and estuarine floodplain; active subsidiary channels and flood deposits	*Floodplain* – sedge fen/reed swamp and salt marsh with alder occupying drier areas *Dryland* – *Quercus/Tilia* dominated mixed deciduous woodland	Mesolithic	Early Holocene
Lower Alluvium – sandy	Massive sand	Freshwater[a]	Large braided river – bar top flood deposits and inter-bar channels	*Floodplain* – sedge fen/reed swamp and salt marsh with alder occupying drier areas[a] *Dryland* – *Pinus/Betula* woodland replaced by *Quercus/Tilia* dominated mixed deciduous woodland[a]	Mesolithic	Late Devensian/Early Holocene
Shepperton Gravel *surface level: −4.58 m OD*	Sandy Gravel	Freshwater[a]	Large braided river – active gravel bars	*Floodplain* – sedge fen/reed swamp[a] *Dryland* – *Pinus/Betula* woodland and tundra[a]	Early Mesolithic, Upper Palaeolithic	Late Devensian Lateglacial; Deposition ceased *ca.* 10,000 cal BP

[a] Suggested vegetation communities and salinity based upon correlation with nearby sequences and regional data (e.g. Devoy, 1979; Thomas and Rackham, 1996; Wilkinson et al., 2000; Batchelor et al., in press-b).

The thickness of the Lower Alluvium is greatest where it forms the lower part of the infill in the channels to the north and south of the Barking Eyot, notably in the enclosed depressions B, J and K. The bulk of this material is likely to have accumulated in the Early Holocene in depositional environments less energetic than those associated with the Shepperton Gravel. There is very little evidence to indicate the exact nature of the Early Holocene depositional environment in the Lower Thames Valley but the sparse diatom floras and potential saline-tolerant species in the pollen record indicate estuarine conditions and therefore the possibility of sediment influx and redistribution in association with estuarine flooding. The overall effect of the accumulation of the Lower Alluvium was to reduce the inequalities of the relief inherited from the surface of the Shepperton Gravel, thus foreshadowing a pattern of deposition that prevailed throughout the rest of the Holocene.

4.2.3. Peat

Dating of the peat that overlies the Lower Alluvium indicates that peat formation began in places where the surface of the Lower Alluvium was low-lying and/or poorly drained, for example below −5.0 m OD in the channels on either side of the Barking Eyot and below −5.5 m OD in the more westerly hollow (Area J) in the northern channel. The earliest date for the onset of peat formation, obtained during the present investigation is 6270–5990 cal BP, from a level of −3.6 m to −3.5 m OD in Borehole H4, located on the southern flank of the Barking Eyot just below the cut-bank described above, probably on an erosional bench abutting and associated with the cut-bank. This date is similar to dates obtained at similar levels nearby, both upstream and downstream from Barking, e.g. respectively at the Cable Car site on the Greenwich Peninsula (Batchelor et al., in press-b) 6290–6030 cal BP at −3.18 to −3.28 m OD; and at the Pirelli site in Erith (Young, 2012) 6280–6030 cal BP at −3.02 to −3.06 m OD. At both these sites, as at Barking, separate organic/peat horizons were present at lower levels, below −5.5 m OD. The dates obtained from these lower horizons varied considerably, but in some cases were not very much older than those obtained at higher levels, e.g. at the Pirelli site 6930–6750 cal BP at −7.06 m to −7.11 m OD.

This evidence suggests that in some places at least, the accumulation of Lower Alluvium was relatively rapid. It also suggests that the potential for peat formation existed throughout the Early Holocene. This was probably partly in response to the rising groundwater-table associated with the Postglacial rise of relative sea level, but was probably also favoured by the survival of poorly drained depressions at various levels on the valley floor, reflecting the inequalities inherited from the surface of the Shepperton Gravel. If both these factors were influential, then exactly where and when peat began to form will have depended on topographic factors affecting both the level and the hydrological conditions of individual localities. Thus, although discrete bodies of peat may be present in the Barking area at different levels OD, it is probably inappropriate to seek direct comparisons with the sequences described by Devoy (1979) in the lower estuary where the influence of changing relative sea level may have been more dominant (see also Haggart, 1995; Long et al., 2000). Once peat formation had begun, the preservation of peat horizons and the uninterrupted accumulation of peat will have depended on formation away from areas of erosion associated with active channels and away from areas affected by large influxes of mineral sediment. Only when the rate of relative sea level rise slowed sufficiently to limit erosion and deposition largely to the main active channels, did the formation of peat become increasingly widespread, extending from low-lying and/or poorly drained areas on the surface of the Lower Alluvium to create a continuous mantle of peat across most of the present site. The evidence outlined here makes it clear that the base of the peat must be diachronous and is likely therefore to record widely different dates for the initiation of peat formation.

Radiocarbon dating of the peat indicates that the later stages of its expansion occupied the interval between *c.* 4400 BP and *c.* 3200 BP. The only large area where the peat is thin and patchy is the highest part of the Barking Eyot, where the surface of the Lower Alluvium is above *c.* −2.0 m OD. This area must therefore have remained dryland for most of the period of peat formation. The thick and unbroken accumulation of peat in the channels on either side of the Barking Eyot shows that during the period of peat formation these low-lying areas were no longer occupied by substantial active water courses. However, the presence of a fine-grained mineral component, generally about 20%, in all of the peat sequences examined in this investigation shows that much of the valley floor was still susceptible to flooding. In the pollen flora associated with the peat, there is little indication of saline conditions, so it seems likely that during the period of peat formation the valley floor of the Thames in the Barking area was a predominantly freshwater environment. There is also evidence to suggest that the peat surface became progressively drier from about 5000 cal BP until after 4000 cal BP. During this interval the pollen and plant macrofossil record shows that yew and later elm became significant components in the floodplain woodland, suggesting a transition from wet fen carr to more mature fen woodland. The findings of the present investigation do not contribute directly to an explanation of how this transition from predominantly tidal to predominantly freshwater conditions came about at this time. However they do show that changing relative sea level may have been less significant in the Barking area than further downstream. In seeking an explanation therefore, it will be important to pay greater attention to factors in the wider catchment of the Thames affecting the behaviour of the river. Such factors include discharge and sediment availability and more indirectly, soil maturity and vegetation type and cover, all of which must have contributed significantly to changes in the wider landscape in the Early to Mid-Holocene.

In the Barking area, the overall effect of peat accumulation was to reduce further the topographic inequalities inherited from the surface of the Shepperton Gravel. This is very clearly illustrated by comparing peat thickness (Fig. 3(b)) with the contours on the surface of the Lower Alluvium (Fig. 2(b)).

4.2.4. Upper Alluvium

The transition in the Lower Thames Valley from peat formation to the deposition of the Upper Alluvium is generally explained as a result of a renewed increase in the rate of relative sea level rise (e.g. Sidell, 2003). This explanation is supported at Barking by the evidence of largely estuarine diatom floras recorded from the Upper Alluvium and by evidence in the pollen record for the reduction of fen carr woodland and expansion of sedge fen/reed swamp communities and saline-tolerant species. In some places the transition appears abrupt with silty alluvium containing no visible organic remains resting directly on the peat. In other places organic remains are common in the lower part of the Upper Alluvium. These differences almost certainly indicate the presence of diachroneity at the base of the Upper Alluvium, but they are probably of very local significance, reflecting local variations in the patterns of erosion and deposition during the period in which the Upper Alluvium was deposited.

Comparison between the thickness of the Upper Alluvium (Fig. 3(c)) and the contours on the surface of the Peat (Fig. 2(c)) shows very clearly that the overall effect of the deposition of the Upper Alluvium was to eliminate almost completely the last vestiges of the floodplain relief inherited from the surface of the Shepperton Gravel. This outcome was achieved despite the likelihood that the accumulation of the Upper Alluvium will have led to significant compression of the underlying peat (Haggart, 1995). This pattern of deposition, and the fine-grained nature of the Upper Alluvium, indicate that deposition was largely from suspension in standing or very slow moving water. There is no indication of significant erosional reshaping of the valley floor that might indicate the presence in the area of a substantial active channel. It follows therefore that throughout the period during which the Upper Alluvium was deposited, the area of investigation formed part of the floodplain of the Lower Thames subject to estuarine inundation but relatively remote from the main active channel which no doubt lay to the south of the site.

5. Conclusion

This investigation of Holocene landscape evolution on the valley floor of the Lower Thames at Barking demonstrates the level of topographic detail that can be achieved in the study of stratigraphic boundary surfaces relying on deposit models based mainly on archive borehole records spaced at approximately 100 m intervals. In the Thames valley-floor environment with relief inherited from a braided or wandering river system, these dimension make possible the recognition of second and third order landforms representing former bars and channels (Miall, 1996). The main elements of this relief are a broad gravel 'swell' aligned approximately WNW-ESE, termed here the Barking Eyot, and the channels on either side of this feature.

Examination of sedimentological evidence recorded in borehole logs at Barking together with the results of detailed palaeoenvironmental and geochronological analysis of selected cores has shown how depositional environments and the wider landscape have changed at Barking during the Holocene. Thus, at the end of the Late Devensian the Barking site was occupied by active elements of a braided or wandering river system that created a pattern of bars and channels with a relative relief of *c.* 5.0 m, represented by the surface of the Shepperton Gravel. This pattern of relief was a dominant influence in the shaping of the valley-floor landscape throughout the Holocene; there is therefore a strong case for developing a regional model of this surface for the Lower Thames Valley using the deposit modelling procedures adopted in the present investigation and identifying all the main elements of the relief.

Early in the Holocene the main active channels within the site appear to have been abandoned and there is no evidence of any substantial erosional re-shaping of the valley-floor relief within the site later in the Holocene. Instead, successive phases of deposition progressively buried and eventually obliterated the relief inherited from the surface of the Shepperton Gravel. The influx of greater or lesser amounts of fine-grained minerogenic sediment which is recorded across the site throughout the Holocene indicates deposition from slow-moving or standing water. Such deposition was probably associated with episodic, estuarine or riverine inundation. In most places therefore inundation was temporary, most likely on a seasonal basis, and it seems likely that for most of the Holocene most of the valley floor at the Barking site was occupied by terrestrial or semi-terrestrial habitats.

The palaeoenvironmental record from Barking confirms important details of the Holocene record observed elsewhere in the Lower Thames Valley, including the presence of *Taxus* in the valley-floor fen carr woodland between about 5000 and 4000 cal BP, and subsequent growth of *Ulmus* on the peat surface. The history of peat formation at Barking has also been reviewed in the context of records from nearby sites and the evidence seems to suggest that where and when peat formation commenced was not simply a response to the Postglacial rise of relative sea level, but was also influenced by the topography and hydrological conditions of the valley floor. In particular, deep enclosed depressions in the surface of the Shepperton Gravel, especially those located near the edge of the floodplain and unaffected by erosion or deposition in active channels, may have the potential to preserve thick peat sequences providing long continuous records of Holocene landscape change on the valley floor and adjacent higher ground. Future investigations in the Lower Thames Valley should seek to locate and sample such localities.

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