Chapter 6
Desk-top Investigation

The Desk-top Assessment

The data sources available to geoarchaeologists investigating the alluvium of the Thames, or any major river valley, can be listed:

- Bedrock and drift (Quaternary) geological maps (supplied by the British Geological Survey – BGS);
- Borehole data acquired for geotechnical ground investigation purposes (held by the Geotechnical Management Unit – GMU);
- Geomorphological map data (held by the GMU);
- Remote sensing data (including air photographs);
- Sub-surface geophysical data;
- Historical Environment Record data and other published records (held by English Heritage/ County Planning Departments);
- Field map, sequence logging and section drawings and descriptions.

Baseline geological maps from the BGS were utilised to outline the study areas and define the nature of the sequences likely to be present beneath the surface of the floodplain. This information acts as the prime source of data in determining the focus of the investigation as well as a first order indication of the likely nature of the sub-surface conditions and potential associated archaeology. Allied to this, and providing detail on the specific nature of the alluvial stack at a given location, were the borehole data obtained for geotechnical ground investigation as part of the project and held by the GMU. This data was archived and supplemented by additional data throughout the life of the project (a good example of the complexity in data gathering throughout the project lifetime is the Ebbsfleet area – see Wenban-Smith *et al* forthcoming). One of the major difficulties faced during the project was keeping up to date with new information from ground investigations, particularly once construction commenced, as responsibility for ground investigation switched from the GMU to the individual contractors. Other forms of data such as the geomorphological map data and remote sensing data were of limited use on the alluvial sector reported here (more use was made of this data on Section 1 of the project within the Kent sector). Limited sub-surface geophysical data was available and the HER of limited use only.

A Geoarchaeological Model for the Study Area

In this project, the evolution of the Thames floodplain area was viewed through a series of stages corresponding to major changes in process through time (Fig 14). In order to evaluate the geoarchaeological potential of the route corridor, a model was constructed that attempts to define some of the principle changes taking place within the area during the Late Pleistocene/Holocene time frame. A number of key points are noted:

- Human activity patterns vary across the landscape;
- Settlement sites are typically restricted to contemporary dry ground away from wetland/ inundated areas;
- Ecotonal zones within the landscape are often areas of intense human activity due to the resource abundance. A major ecotonal boundary is recognised as that between dry and wet ground;
- Wetland activity by humans is often ephemeral and related to resource exploitation (eg, traps and trackways) with the exception of unusual sites such as ritual sites and platforms (Pl 5);
- Coarse flint gravels deposited under periglacial conditions (Pl 6) are likely to contain only reworked flint artefacts of Pleistocene date;

Plate 5 Trackway from excavations along the A13 DBFO Road Scheme at Woolwich Manor Way, Newham

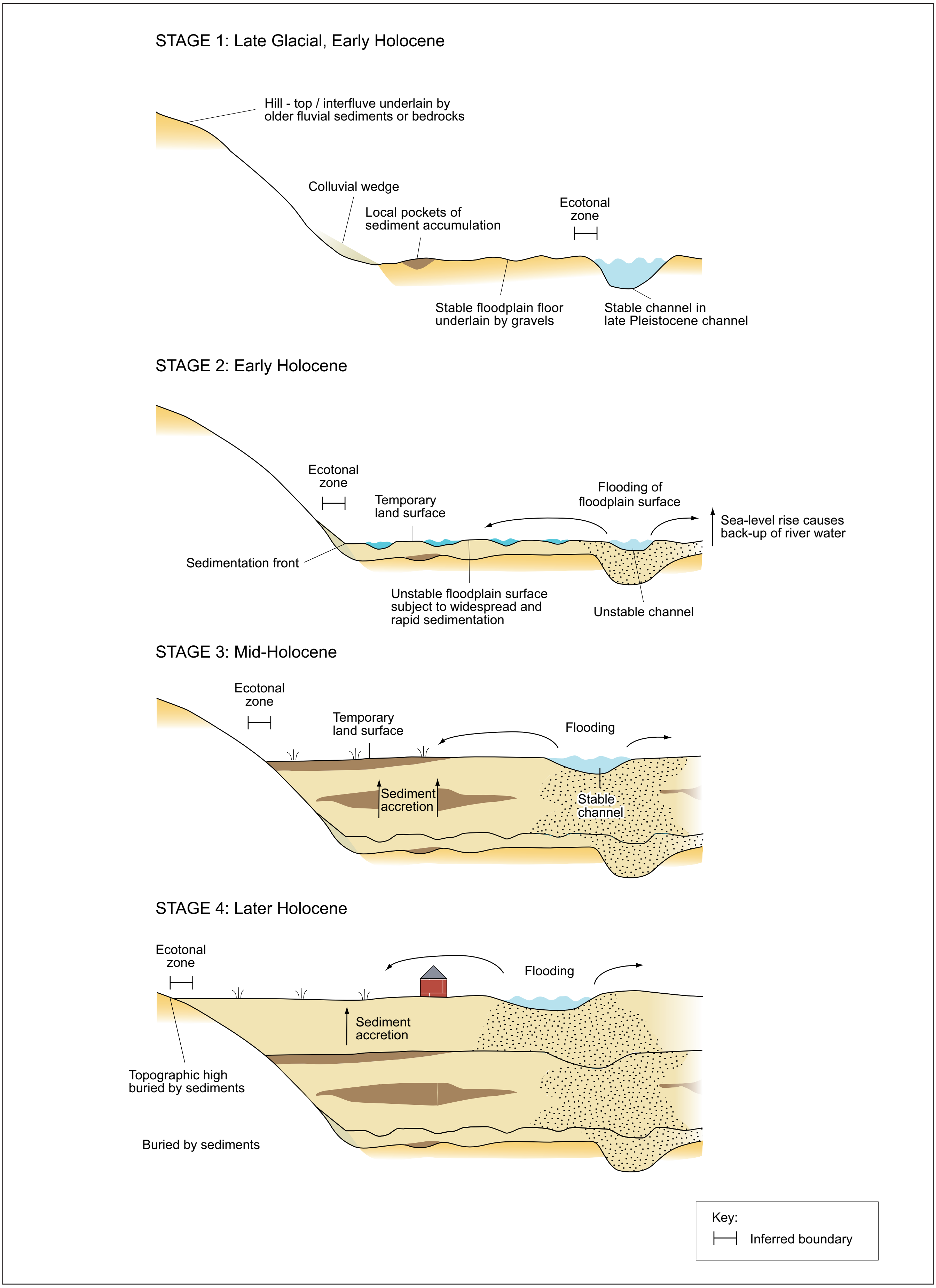

Figure 14 Simplified evolutionary model of the Thames floodplain area used in this study from the Late Glacial to the later Holocene (from Bates 1998)

- A major buried landsurface exists at the boundary between the coarse grained, cold climate periglacial deposits and the overlying Holocene sediments (Pl 7);
- Peat/organic silt accumulation occurs during times of wetland emergence with little or no minerogenic input (Pl 8);
- Minerogenic sediment deposition occurs during phases of relatively higher energy conditions including those driven by rising sea-level or within deeper water;
- Colluvial sediment wedges (colluvium consists of bodies of sediment located at the base of slopes through downslope movement caused by gravity) occur at the boundary between wetland and rising dry ground areas;
- Lithological units (typically used as the primary stratigraphic units in geoarchaeological evaluations) are likely to be time transgressive and careful consideration of the significance of the lithostratigraphic correlation should be undertaken.

These stages (modified from Bates 1998) were:

Stage 1a: Late Glacial

This phase, during sea-level low stand, is characterised by cold climate periglacial activity and coarse gravel/sand aggradation in the incised valley bottom. Within the area of investigation a deeply incised valley would have existed, flanked by higher ground, capped by older fluvial sediments from earlier episodes of sand and gravel aggradation. Exposed bedrock surfaces may also have existed on the valley sides. Areas of higher ground bedrock, possibly capped by older fluvial sediments, may also have existed within the floodplain area (Fig 14.1).

Sedimentation in the valley bottom would have been characterised by fluvially deposited coarse gravels and sands with soliflucted sands, gravels and silts at the margins of the floodplain blanketing the valley sides. These deposits would have consisted of bedrock mixed with older Pleistocene sediments and possibly aeolian inputs.

Stage 1b: Early Holocene

During this phase, following climatic amelioration, but prior to sea-level rise, the area would have been characterised by relict Late Glacial features (see above) with a stable channel within the old Late Glacial main channel. The floodplain of the river adjacent to the main channel would have stabilised with the development of the Holocene vegetation and probably formed a relatively dry ground area. Higher gravel areas existed as 'islands' of isolated older Thames gravels in the floodplain and on the valley sides (Fig 14.2).

A key ecotonal area probably existed adjacent to the main Thames channel and any floodplain tributaries. Higher ground would have provided additional landscape resources within different environments.

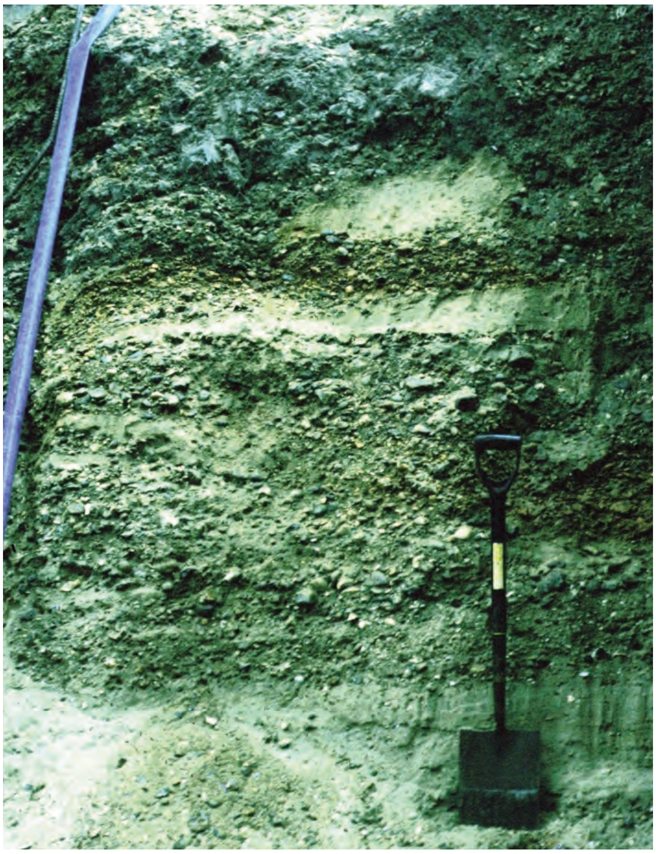

Plate 6 Cold stage gravels exposed during excavations at Liverpool Street Station, Central London, in the early 1990s

Plate 7 Buried surface at top of gravels, HS1 Swanscombe

Plate 8 Peat and clay-silt within alluvium, HS1 Swanscombe

Plate 9 Sand and gravel island within alluvium, Colne floodplain, Longford, Heathrow

Stage 2: Early Holocene

During this stage sea-level rise begins to influence sedimentation and fluvial dynamics within the valley floor area. As sea-level rises channel stability decreases and flooding of floodplain areas begins due to backing-up of fluvial water behind the landward migrating estuarine front. The floodplain surface becomes unstable due to widespread flooding and rapid sedimentation. Minerogenic sedimentation probably characterises this phase, burying the former dry floodplain surface (Pl 7).

During this period the ecotonal zone between wet and dry ground migrates inland and rises in datum across the flooding surface. This boundary also represents the position of the maximum landward projection of the zone of wetland sedimentation on the topographic template at any datum or time, and is called the sedimentation front. Thus wetland environments begin to expand at the expense of the dry ground areas. Temporary landsurfaces may exist within the flooding area but these are likely to be ephemeral and of local, short duration, significance only. Dry ground areas remain as 'islands' within the wetland and at the margin of the wetland zone (Pl 9).

Stage 3: Middle Holocene

This phase is characterised by apparent fluctuating rates of sea-level rise in which alterations between organic and inorganic sedimentation dominate the area (Pl 8). Temporary emergence of surfaces at or above flooding level stimulate the growth of organic sediments and lead to peat growth. Peat growth subsequently expands as channel stability is regained after initial flooding.

The ecotonal zone between wetland and dryland continues to move inland and topographic variation is lost. During times of peat accumulation complex boundaries between peat and non-peat wetland ecosystems emerge within the wetland. Wetland now dominates in the floodplain area as dry ground zones shrink rapidly (Fig 14.3).

Stage 4: Later Holocene

This phase is characterised by the final submergence of the former floodplain topography and the loss of much of the floodplain diversity. Typically organic sediment growth appears to cease after topographic elevation is buried.

This model accounted for the patterns shown in Figure 13 from the Barking Reach area at the scale of the operational landscape and it is noted that this model refers primarily to the process by which former floodplain topography is inundated and lost. However, locating the exact position of the dry ground/wet ground interface is problematic at a site specific level because this will shift seasonally as well as with changing local topographic position (eg, in relation to the position of active channels). Consequently, this was a best guess for understanding landscape scale change within the region but not a precise reflection of position at the site level. It is also difficult to determine the relationship between submergence of the floodplain topography and changes within the wetland at some distance from the dry ground/wet ground boundary. This is primarily a result of problems in correlating between these two areas caused by lateral facies variation and the problems of autocompaction of the peat (Allen 1999).

Chronological Control

In order to determine the timing of on-set of sedimentation onto the topographic template radiocarbon age estimates (uncalibrated radiocarbon years (^{14}C BP), this convention is used throughout the volume and compared against calibrated (cal BC/AD) dates where appropriate) were selected from situations where organic deposits immediately overlie the Pleistocene gravels or sands (ie, where minimal sediment compaction is likely). All radiocarbon age estimates from contexts where peats were present within stacks of unconsolidated sediments were ignored (however, these age estimates are clearly important for defining age relationships within the sediment body).

The selected age estimates were plotted against depth and regression curves fitted to the data (Fig 15; see Bates 1998; Bates and Whittaker 2004 for detailed data). Because of the selection of the data no compaction and distortion of the data has occurred. Two distinct groups of age estimates were identified consisting of an older and younger group of age estimates where a steeper curve was fitted to the older group. This data indicates more rapid rates for the onset of sedimentation occurred prior to *c* 5000 cal BC (*c* 6000 ^{14}C BP) with slower rates thereafter (ie, within the later Mesolithic). The slowing of the rate of onset of sedimentation occurred after attaining datums of *c* -5.0m OD. This sub-division is a function of rising sea-level and the infilling of the accommodation space (ie, sedimentary basin space defined by the shape of the topographic template).

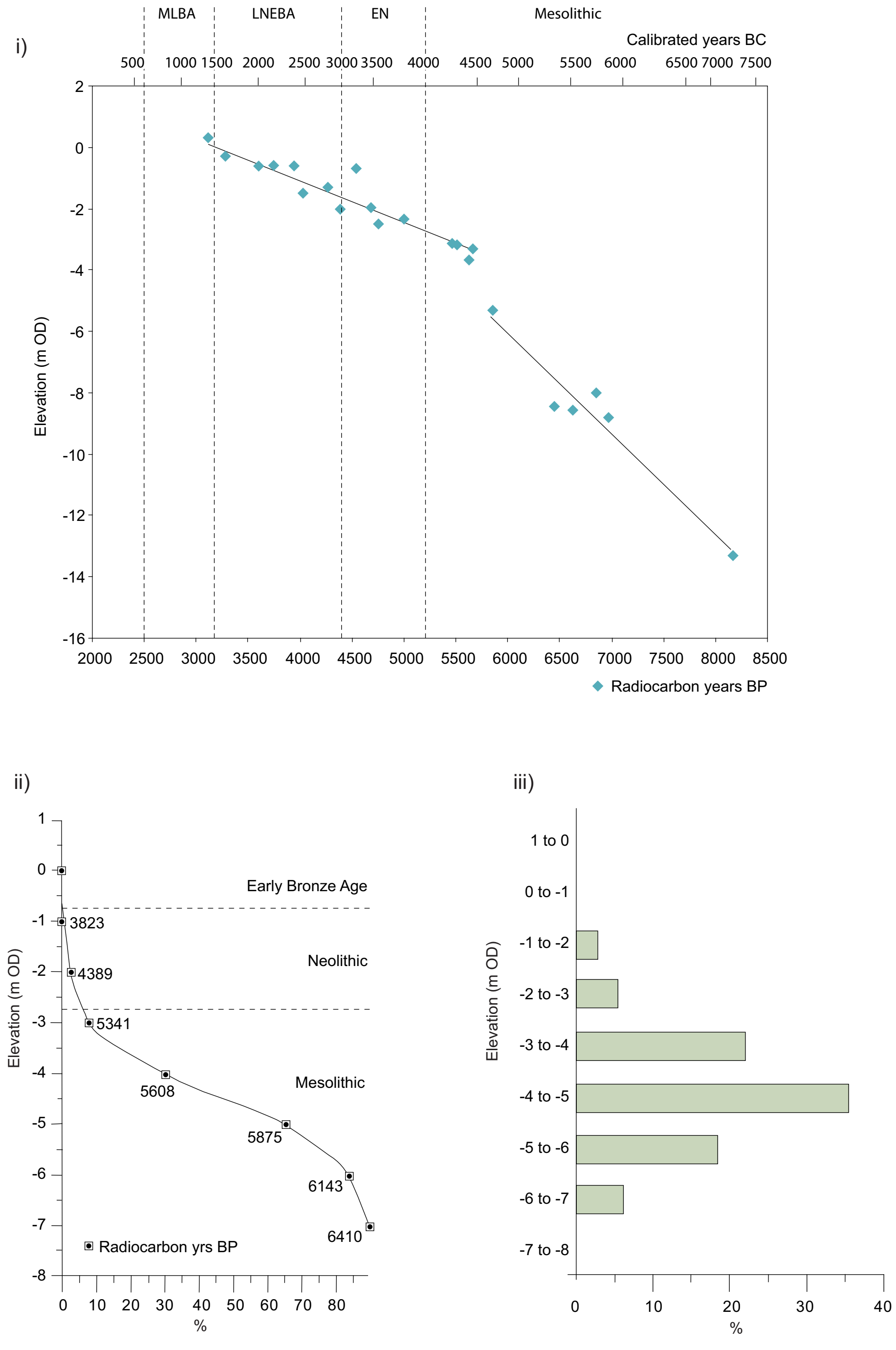

Figure 15 Time/depth model used to calibrate the speed of landscape change on the north Thames floodplain in the area of Barking Reach (from Bates 1998). i) Conventional radiocarbon age estimates (BP) plotted against depth for organic onto gravel situations for selected sites in Lower Thames including trend lines for regression used in calculation of predicated age/depths. This plot shows an initial steeper plot prior to 6000 BP for the phase of rising sea-level followed by a phase of reduced gradient following sea-level attaining maximum elevations. Calculation of the slope of regression lines for each part of the curve allows a time/depth model to be produced. ii) Plot showing the percentage of the gravel surface resting below selected datums. Predicted age estimates (see i above) for specific 1m intervals are shown. This information suggests that only *c* 800 radiocarbon years elapsed between the onset of sedimentation at -6m OD and sedimentation attaining datums of -3m OD. During this time *c* 75% of all former dry ground within the Barking Reach area disappeared. iii) Percentage of the gravel surface between successive 1m contour intervals in the Barking Reach area. This plot shows that the majority of the gravel surface rests between datums of -3m to -6m OD

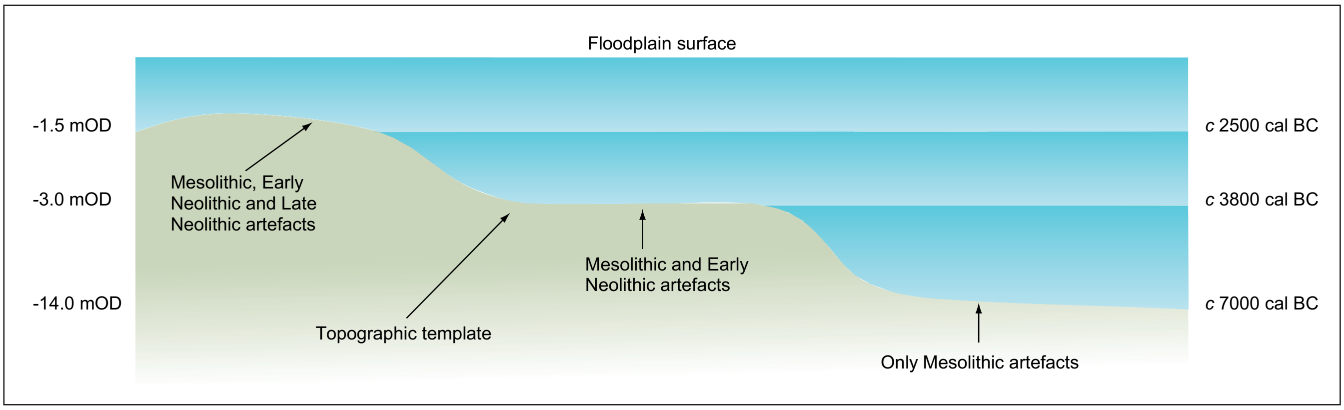

Figure 16 A model for temporal separation of artefact assemblages below floodplain surface based on elevation of the surface of the gravels

The data can be used to define a relationship between age and depth of a deposit at the sedimentation front (ie, the dry ground/wet ground contact on non-compressible substrates). Therefore the speed of inundation of the dry ground topography and the position of the dry ground/wet ground ecotone may be located either at a point on a cross section or spatially on topographic projections.

This relationship is illustrated in Figure 16 where the relationship between the inundation surface, time of inundation and archaeological potential are shown. This model was supported by previous finds from the margins of the Thames floodplain at sites such as Bronze Age Way, Erith (Bennell 1998) and Slade Green (Bates and Williamson 1995).

Subdivision of the Route Corridor

A representative stratigraphy of the route corridor was constructed after careful study of all data sources held by the Geotechnical Management Unit (GMU) at Rail Link Engineering (RLE). A selection of representative boreholes was used to construct the route corridor stratigraphy. The route corridor was divided at an early stage into a series of route windows (Figs 17, 19, 21, 23, 25, 27, 29 and 30), and linked to the distance from the St Pancras terminal end of the route corridor. These route windows were designated and defined by the GMU and provided the initial framework within which the geoarchaeological investigation for the route was conducted. Route windows 1 to 5 were excluded from this investigation at an early stage as it was recognised that they corresponded to areas of bored tunnel within the bedrock and fell outside the alluvial corridor recognised as the defining context for the geoarchaeological investigation. The following procedure was followed for the investigation of each of the route windows:

- A representative selection of borehole logs was selected from the length of each window. Typically 20 boreholes were selected per route window. It should be noted that the length of individual route windows differs. This is modified slightly in the case of the Ebbsfleet Valley where greater complexity in the sedimentary architecture of the deposits was considered likely;
- The stratigraphy was plotted for each borehole and lithostratigraphic correlations were made between adjacent boreholes (Figs 18, 20, 22, 24, 26 and 28). For the Ebbsfleet Valley a fence diagram (Fig 31) illustrates the added complexity of the sequences;
- The stratigraphic profiles were examined in order to determine the position of the topographic template for the Early Holocene (ie, gravel/alluvium contact);
- The route corridor was subdivided into geoarchaeological zones based on the trend of the topographic template, the proximity of the route area to the higher (dry) ground at the edge of the alluvium, the nature of the sedimentary stack and dissimilarities in lithological continuity across space (Figs 17, 19, 21, 23, 25, 27, 29 and 30).

The stratigraphic profiles presented in Figures 18, 20, 22, 24, 26, 28 and 31 are summarised from the borehole information and were used to identify potential within individual windows. The stratigraphy is summarised in *Table 8*.

Window 6: 17.30–18.92km (East Roding Valley)

This section lies between route kilometres 17.30km and 18.92km (Figs 17 and 18). The route corridor lies close to the outcrop of the older, perched, Thames terrace gravels at the western end of the route corridor. Throughout much of this window the route corridor lies at least 200m from the edge of the floodplain and the higher ground underlain by Pleistocene sands and gravels of the East Tilbury Marshes Gravel.

Bedrock throughout this area of the route corridor consists of London Clay. The rockhead surface shows a distinct two-fold pattern with datums at around -5m OD between 17.3km and *c* 17.8km and below -8m OD throughout the remainder of the window. The upper surface of the gravel, ie, the Early Holocene topographic template, mirrors this two fold sub-division with surfaces

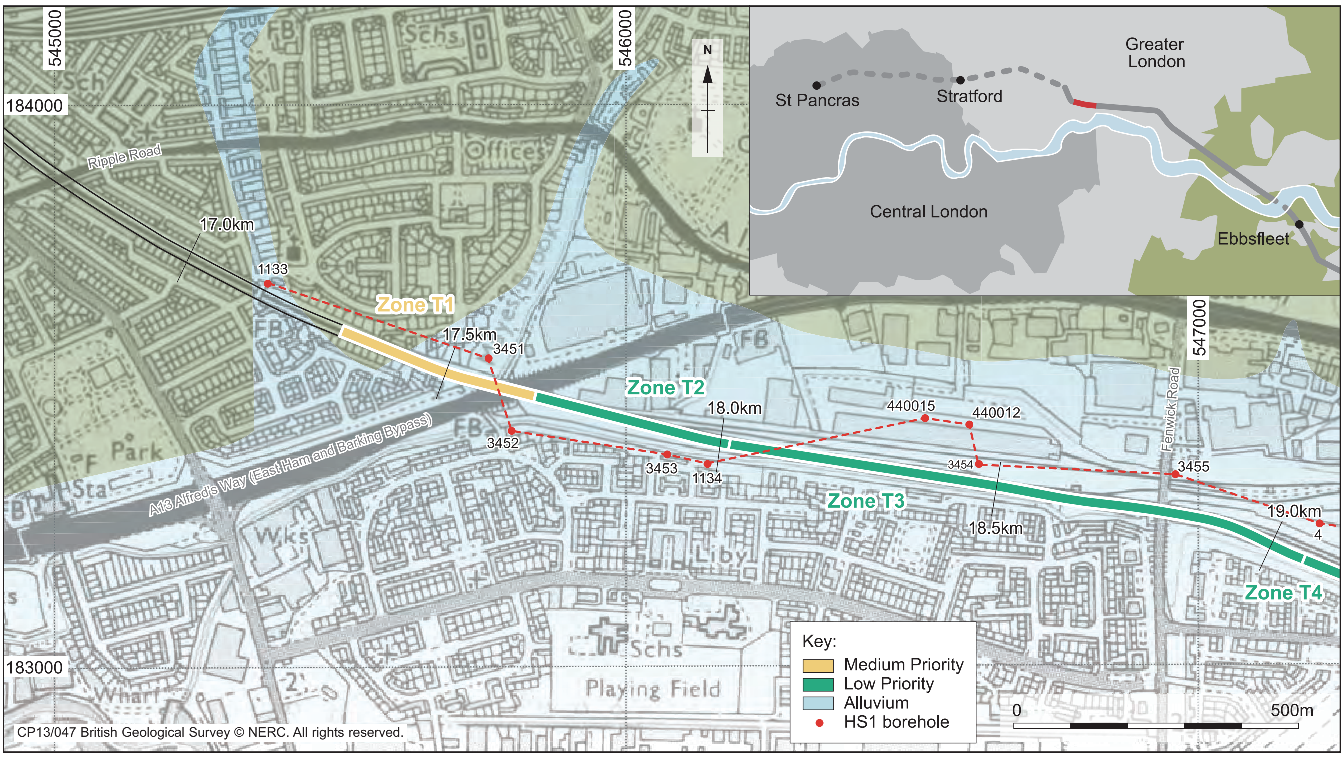

Figure 17 HS1 route corridor Window 6 (Zones T1–T3): location of boreholes

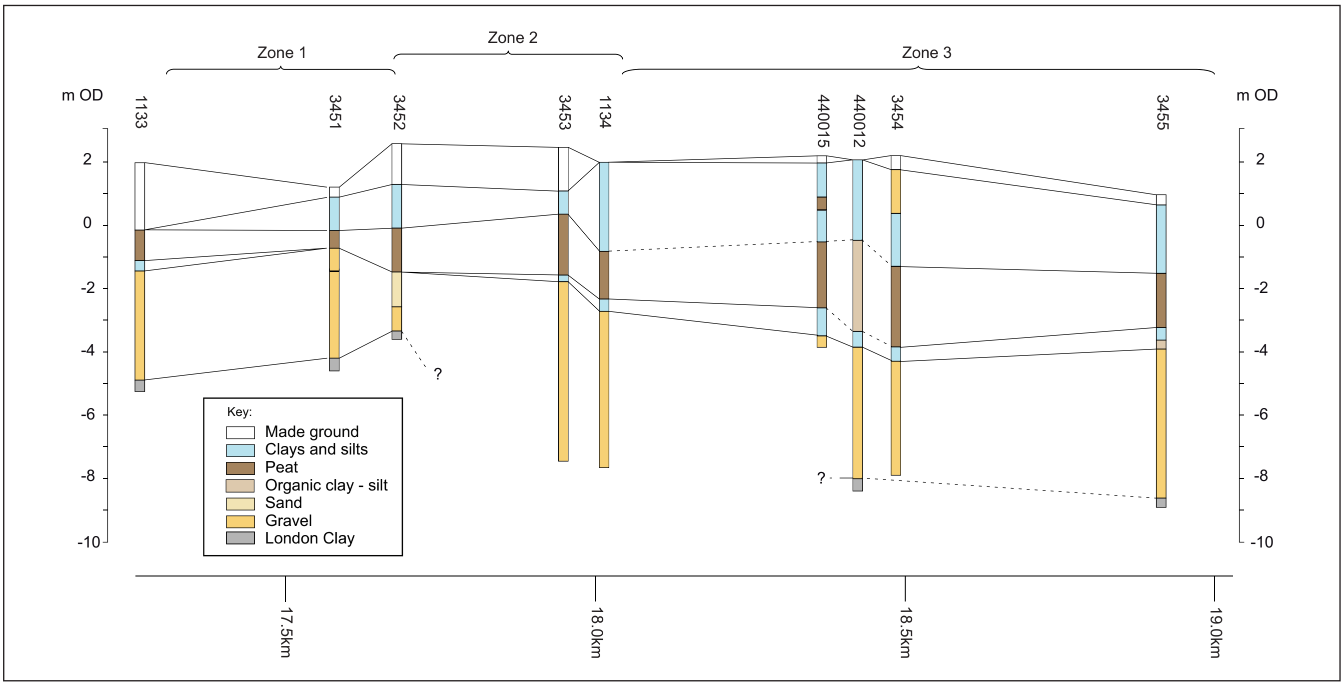

Figure 18 HS1 route corridor Window 6 (Zones T1–T3): lithological profile

at *c* -1.5m OD at the western end dropping to -4.0m OD at the eastern end.

Holocene sediments are dominated by a single major peat unit lying between datums of *c* -0.2m OD and extending to a maximum depth of -4.2m OD. This peat unit can be seen to thin out over the higher gravel towards the west where the peat directly overlies the gravel/sand sequence. Within the eastern part of the corridor peats overlie a thin basal clay-silt. Clay-silts cap much of the peat sequence and made ground is thickest towards the west. A single occurrence of a higher peat unit, extending upwards to *c* 0.5m OD is recorded in a borehole at 18.287km. Three geoarchaeological zones were defined in this area (*Table 8*).

Using the age estimates for onset of sedimentation on the topographic template initial flooding of the eastern end of the route corridor might have occurred during the Late Mesolithic by *c* 4500–4300 cal BC (*c* 5600 ^{14}C BP), with the western end of the route corridor remaining on the whole dry until *c* 2500 cal BC (*c* 4000 ^{14}C BP) at the end of the Late Neolithic period. Zone T2 may have formed an important ecotonal area during the period between 4500–2500 cal BC.

Window 7: 18.92–21.4km (East Roding Valley and West Dagenham Marshes)

This section lies between route kilometres 18.92km and 21.4km (Figs 19 and 20). The route corridor lies between 250m and 500m south of the boundary of the floodplain and the outcrop of higher, older Pleistocene sediments of the East Tilbury Marshes Gravel.

Bedrock consists of London Clay with Woolwich Beds appearing at *c* 21km. The rockhead surface shows a distinct two-fold pattern with datums at *c* -9m OD between 18.92km and 19.5km OD dropping to -10.0m/ -12.0m OD throughout the remainder of the window. The upper surface of the gravel, ie, the Early Holocene topographic template appears to undulate between *c* -3.0m and *c* -6.0m OD.

Holocene sediments are dominated by a single major peat unit lying between datums of *c* 0.0m OD and extending to a maximum depth of *c* -5.0m OD. This peat unit overlies silts, clay-silts, sands or slightly gravelly units where the Pleistocene/Holocene contact lies below -4.0m OD. Peat directly overlies the Pleistocene gravel where the gravel surface extends upwards to -4.0m OD or less. The upper surface of the peat appears to undulate by over 2.0m in places, in particular higher upper surface peat datums are noted where peat directly overlies Pleistocene topographic highs and, to a greater degree, where the overlying sediments are at their thinnest, this feature is therefore probably an artefact of sediment autocompaction (see Allen 1999). Clay-silts cap much of the peat sequence and made ground is thickest towards the east. Five geoarchaeological zones were defined in this area (*Table 8*).

Using the age estimates for onset of sedimentation on the topographic template initial flooding of the lower parts of the route corridor, ie, in Zones T4 and T7, might have occurred by *c* 5000–4800 cal BC (*c* 6000 ^{14}C BP). Zone T5 would have remained generally dry until *c* 4300 cal BC (*c* 5500 ^{14}C BP), possibly as an island within the wetland zone. Two areas of floodplain tributary activity may exist at 19.325km and within Zone T7. However, no trace of channel activity exists within the overlying peat sequences at these points suggesting that the existence of these channels during the Holocene was of limited duration.

Window 8: 21.40–24.39km (Dagenham and Hornchurch Marshes)

This section lies between route kilometres 21.40km and 24.39km (Figs 21 and 22). The route corridor lies south of the outcrop of the higher, older Pleistocene sediments defining the edge of the alluvium. Two major valleys enter the floodplain from the north at *c* 22km and *c* 24km. Additionally, the route corridor appears to approach and possibly impact on the older Pleistocene deposits of the Mucking Gravel at *c* 23.5km.

Bedrock consists of Woolwich/Reading Beds or London Clay. The rockhead surface shows considerable variation in elevation along the window length and ranges from *c* -14.0m OD to -8.0m OD. The upper surface of the gravels shows similar variation in elevation between *c* -3.0m OD and -6.0m OD. Considerable internal variation exists within the gravel sequences suggesting the possible presence of some major channels.

Holocene sediments are dominated by a single major peat unit lying between -2.0m OD and -4.0m OD. The organic silts noted in places may be a local facies equivalent of the peat. Thin clay-silts, silts or sands exist in places below the peat. An upper complex of silts, sands and organic silts exists in the area. Made ground is extensively developed at the *c* 22km mark.

Six geoarchaeological zones were defined in this area (*Table 8*). Using the model outlined above it is likely that all areas of the window were submerged below the sedimentation front between *c* 4800–4300 cal BC (*c* 6000–5500 ^{14}C BP). Features in the Pleistocene gravel sequences indicate the possible position of two major infilled channels of Late Pleistocene age. A major zone of potential archaeological significance exists within Zone T12 coinciding with the location of Rainham Creek.

Window 9: 24.39km to 27.78km (Rainham, Wennington and Aveley Marshes)

This section lies between route kilometres 24.39km and 27.78km (Figs 23 and 24). The route corridor lies close to the Mucking and West Thurrock Gravel at the margin of the floodplain between 24.38km and 24.88km. Beyond this point the corridor lies to the south or east of the floodplain edge. Two valleys enter the floodplain at *c* 25.5km and 26.5km.

Bedrock consists of London Clay or Thanet Sand. The rockhead surface shows considerable variation in elevation along the window length and ranges from *c* -9.0m OD to -15.0m OD, with dips noted where two major valleys bisect the area The upper surface of the gravels shows similar variation in elevation with variations between -5.0m OD and -9.0m OD at the western end to datums of -12.0m OD in the east.

Holocene sediments are dominated by a single major peat unit centred between 2.0m OD and -5.0m OD. This peat unit may locally bifurcate into two or more sub-units. Thick clay-silts, silts, sands and organic units exist below the peat. An upper complex of silts, sands and organic silts exists in the area. Made ground is relatively thin through the length of the window. Three geoarchaeological zones were defined in this area (*Table 8*).

On the basis of the model proposed above it is suggested that initial inundation of the eastern end of the basin would have occurred *c* 6000 cal BC (*c* 7200 ^{14}C BP). The western part of the basin would have been inundated by *c* 6000–5500 cal BC (*c* 7000–6500 ^{14}C BP). Key floodplain marginal ecotones may be identified at the boundary between Zones T14 and T15 and the eastern part of Zone T14 may have acted as an important dry

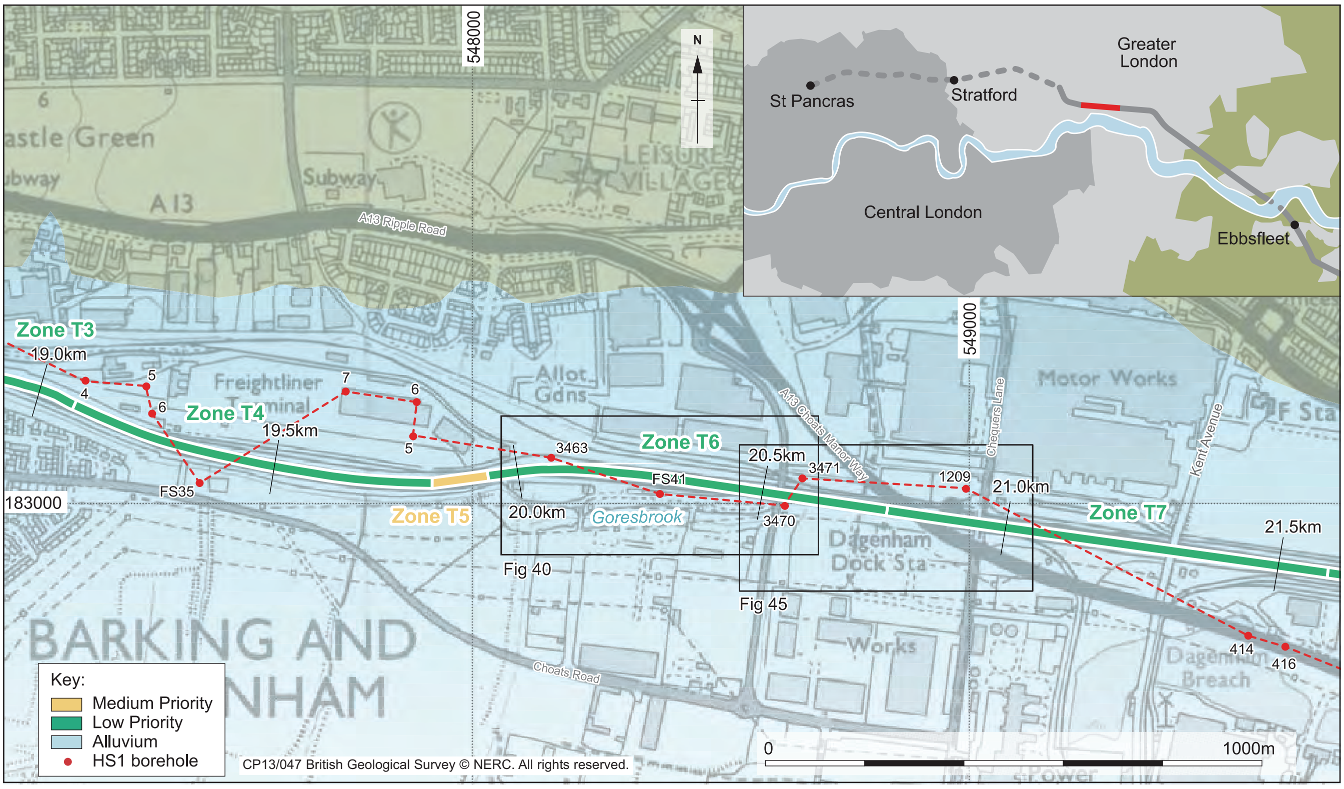

Figure 19 HS1 route corridor Window 7 (Zones T3–T7): location of boreholes

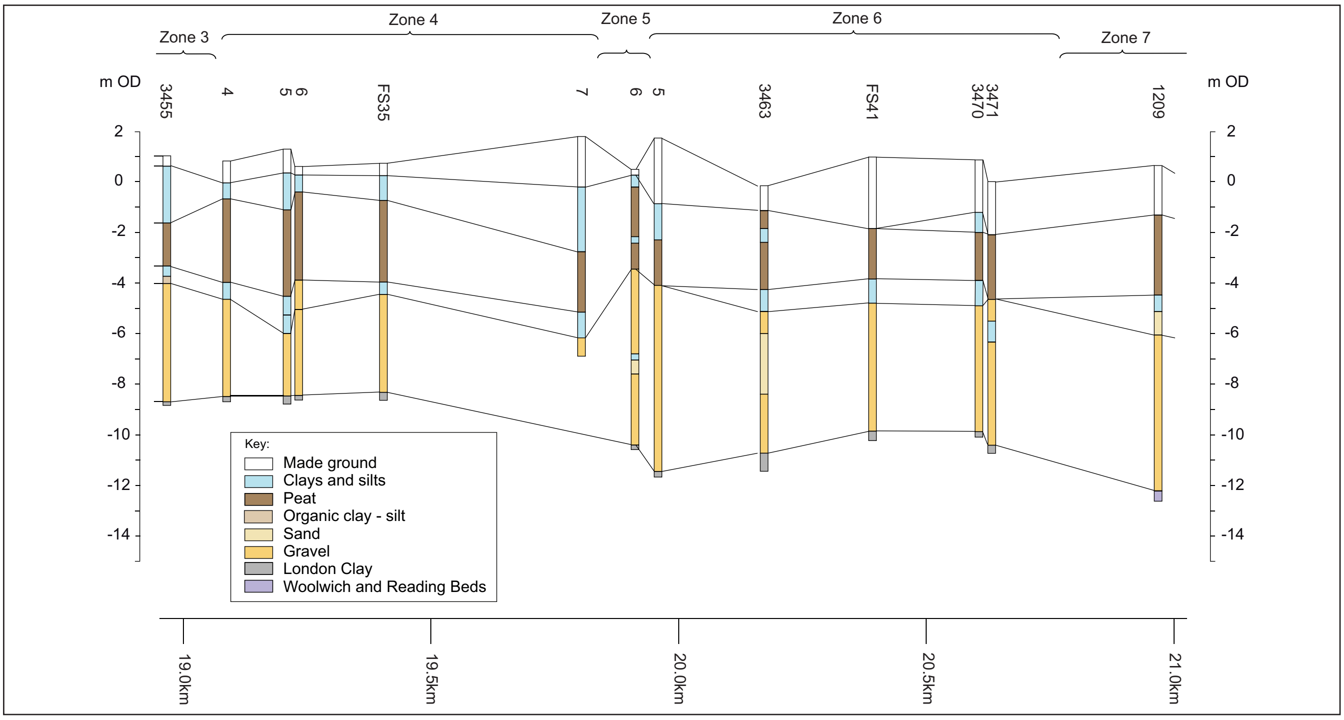

Figure 20 HS1 route corridor Window 7 (Zones T3–T7): lithological profile

ground zone as wetland inundation occurred in Zone T15. Similarly, the western end of Zone T14 may have formed a dry ground region during early infilling of Zone T13.

Window 10: 27.78–28.93km (Aveley Marsh and the Mar Dyke)

This section lies between route kilometres 27.78km and 28.93km (Figs 25 and 26). The route corridor lies across the mouth of the Mar Dyke.

Bedrock consists of Chalk. The rockhead surface shows considerable variation in elevation along the window length and ranges from *c* -5.0m OD at the western end, to -10.0m OD in the central area, climbing to *c* -1m OD at the eastern end, directly correlating with the mouth of Mar Dyke. Gravel is only present at the western end of the route corridor and in a Borehole 3503. Head deposits are noted either side of the Mar Dyke.

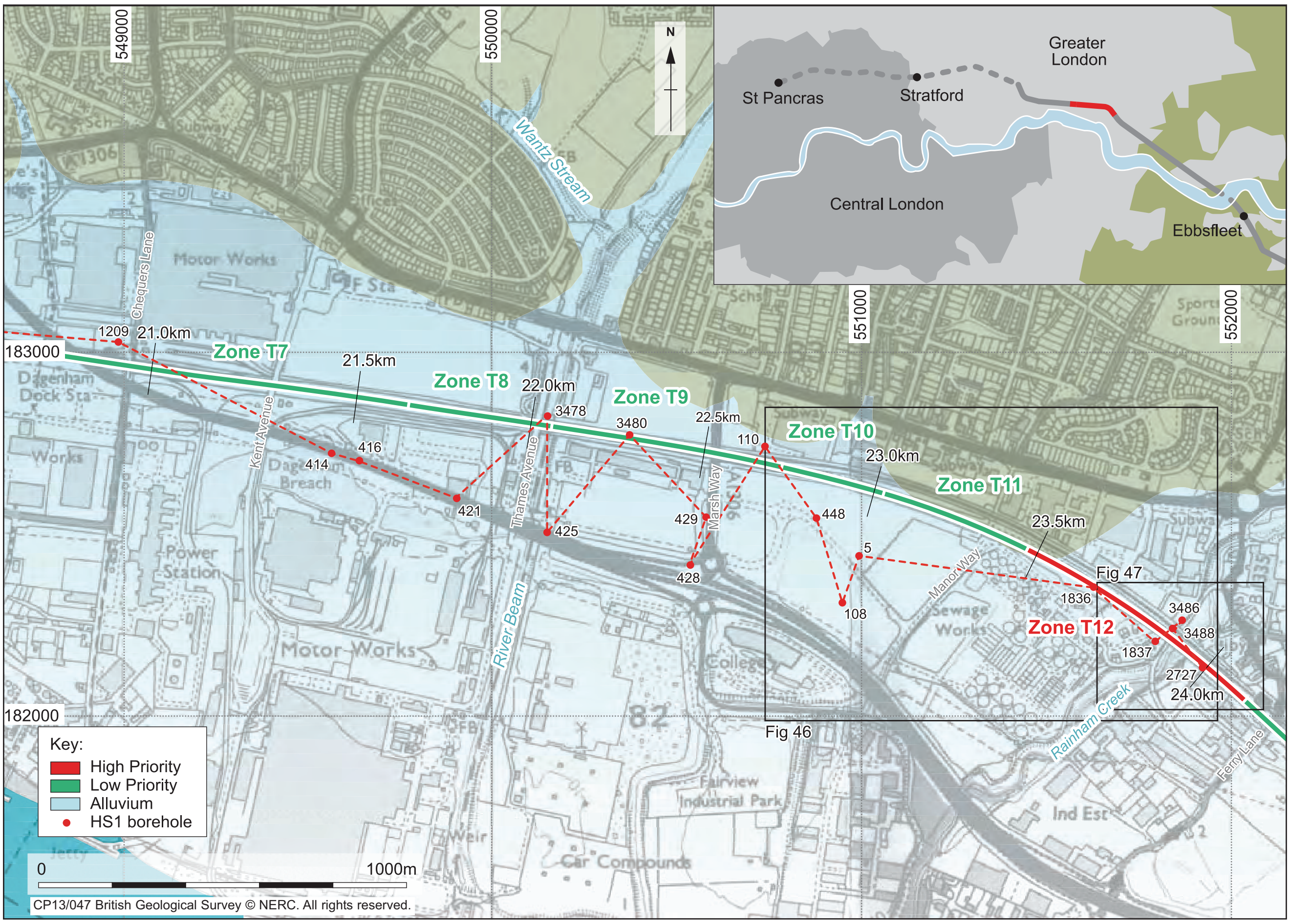

Figure 21 HS1 route corridor Window 8 (Zones T7–T13): location of boreholes

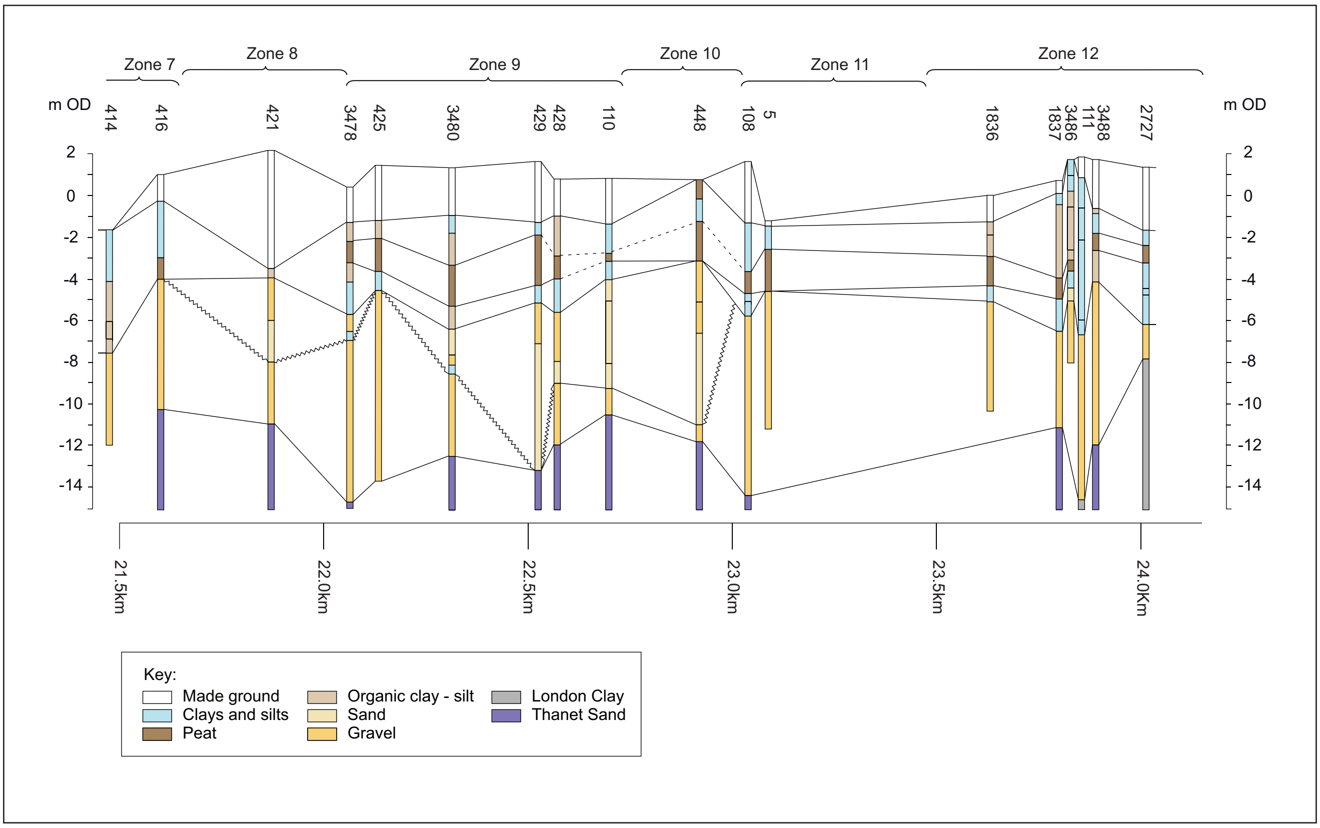

Figure 22 HS1 route corridor Window 8 (Zones T7–T13): lithological profile

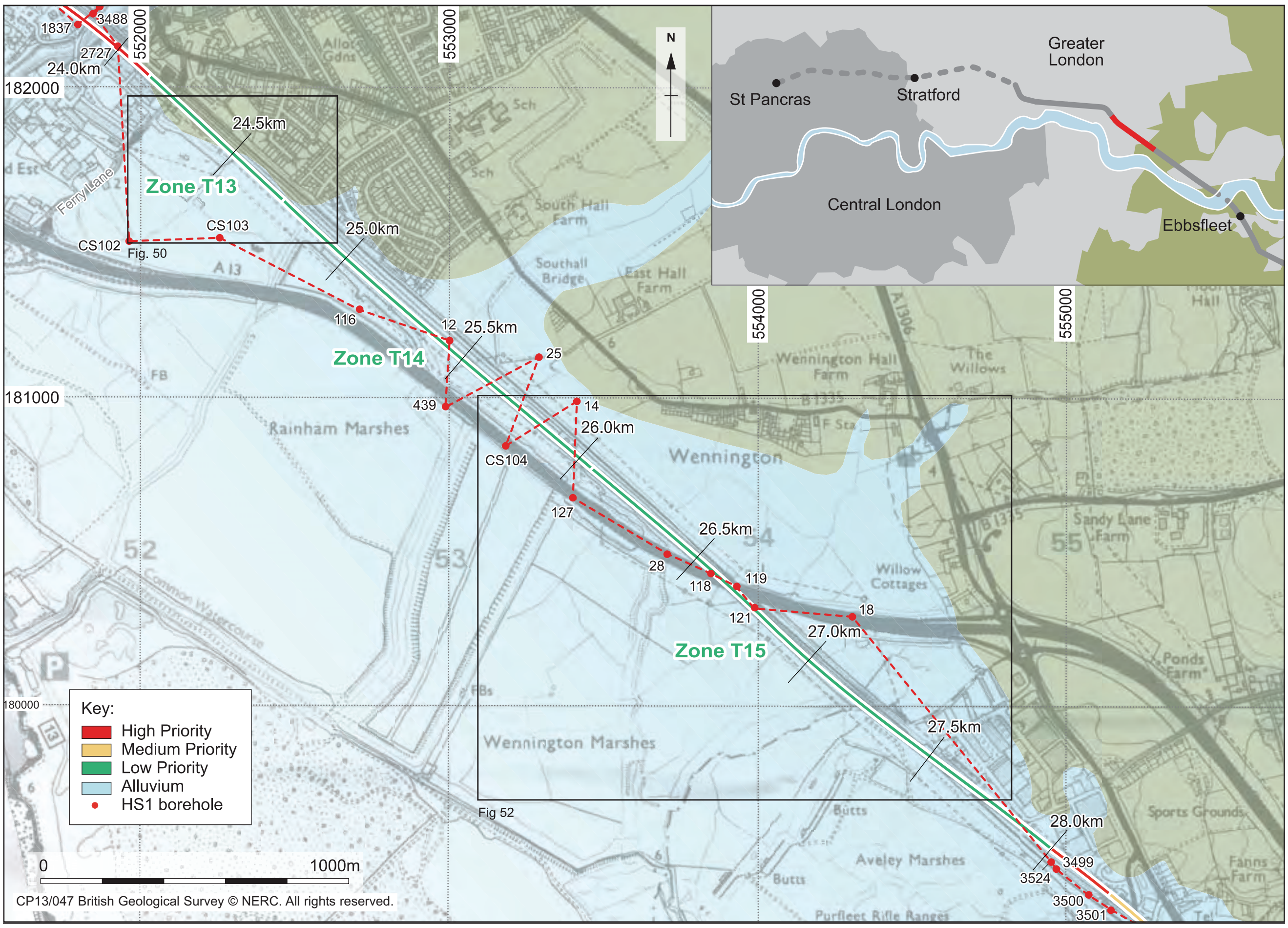

Figure 23 HS1 route corridor Window 9 (Zones T13–T15): location of boreholes

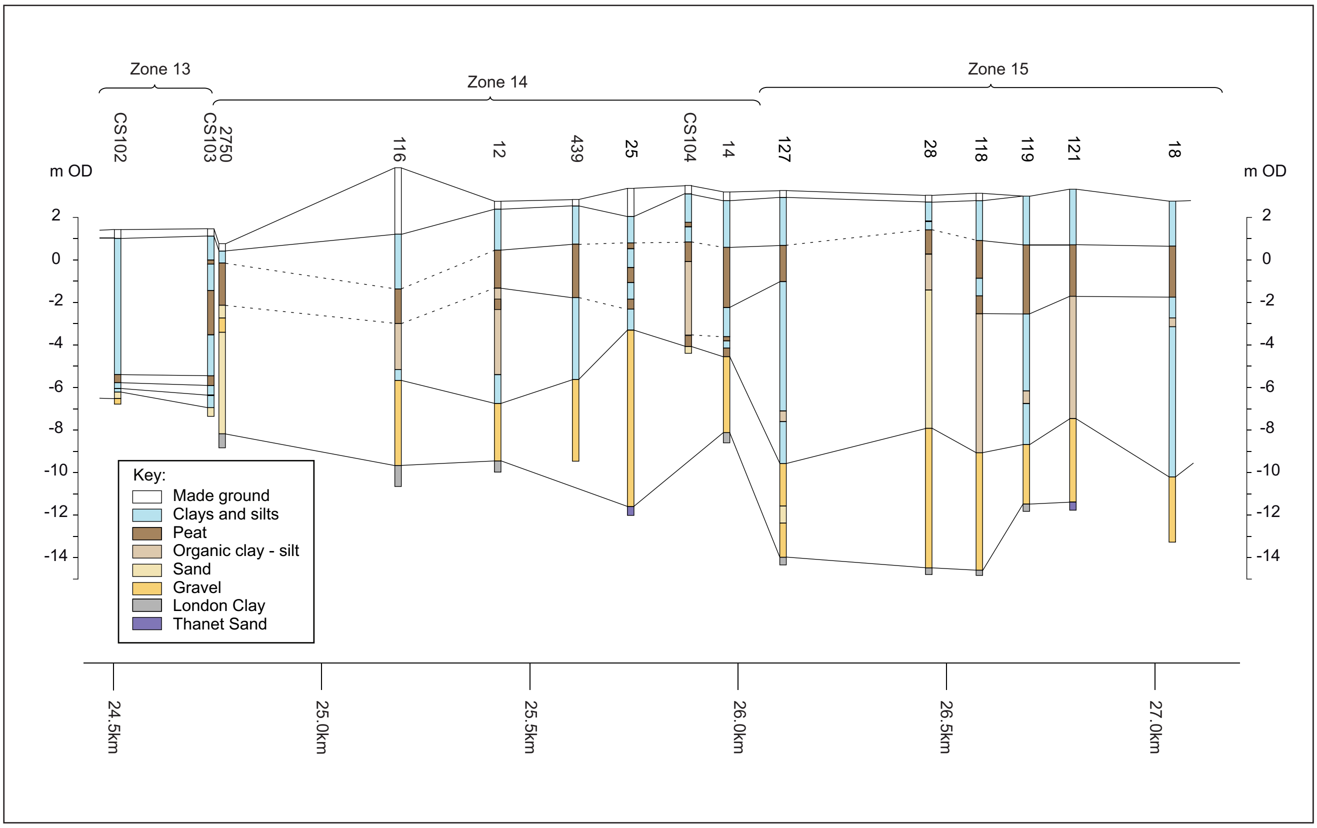

Figure 24 HS1 route corridor Window 9 (Zones T13–T15): lithological profile

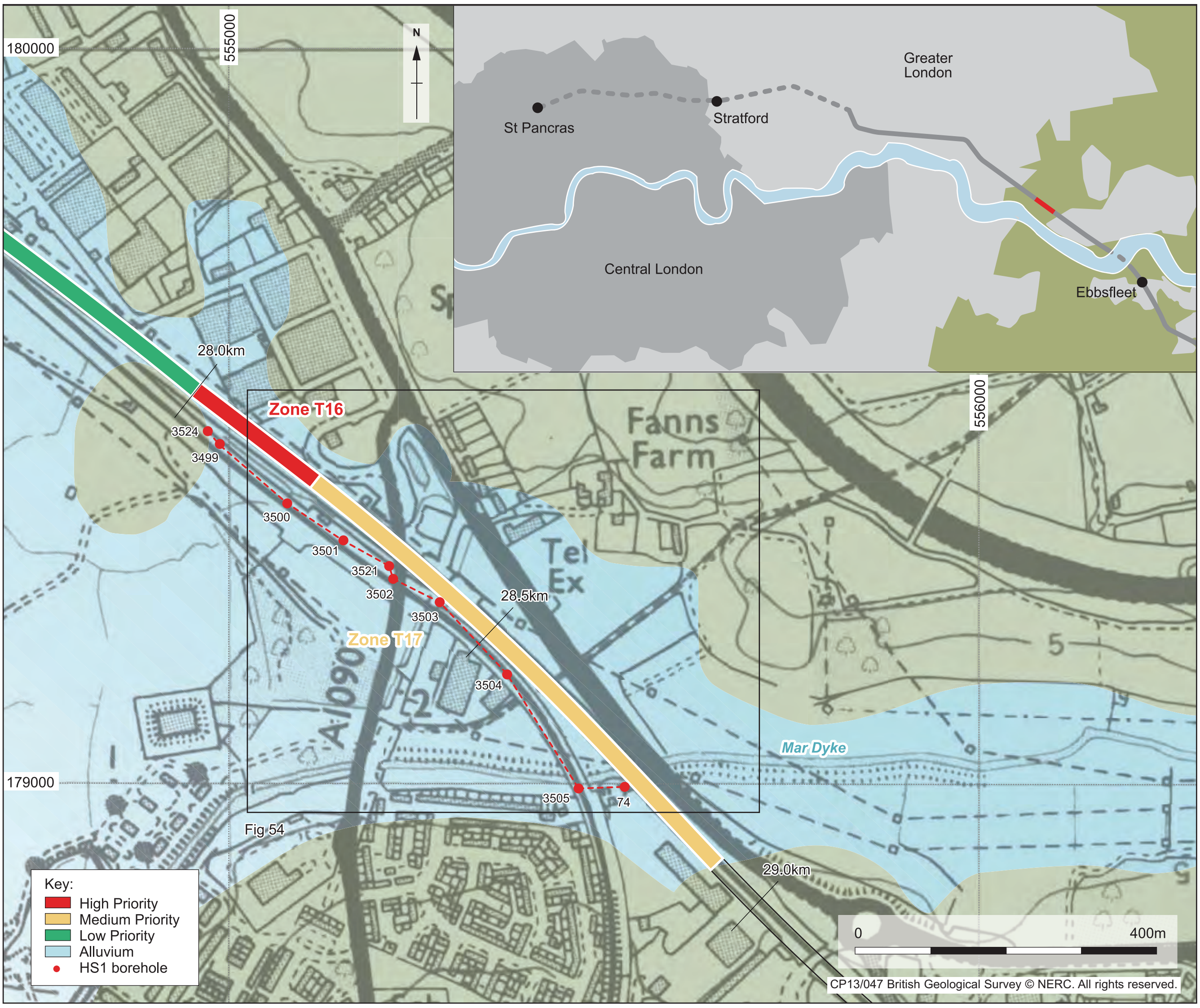

Figure 25 HS1 route corridor Window 10 (Zones T15–T17): location of boreholes

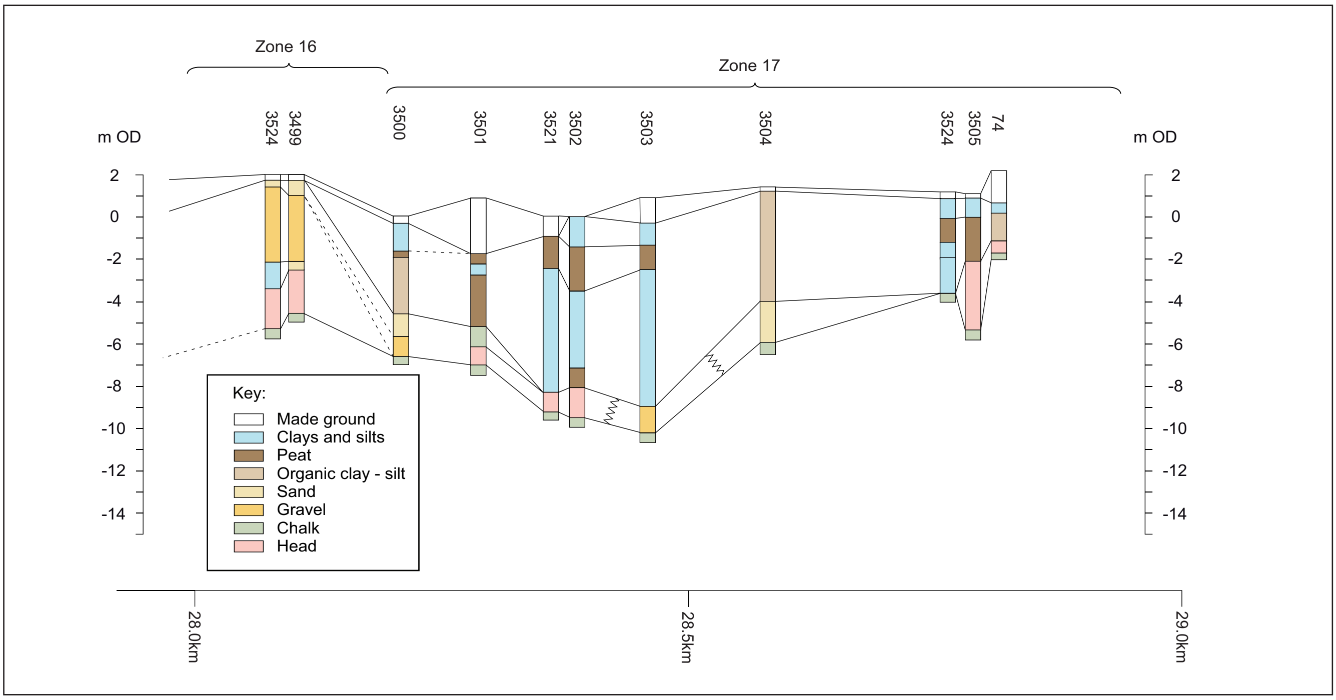

Figure 26 HS1 route corridor Window 10: (Zones T15–T17) lithological profile

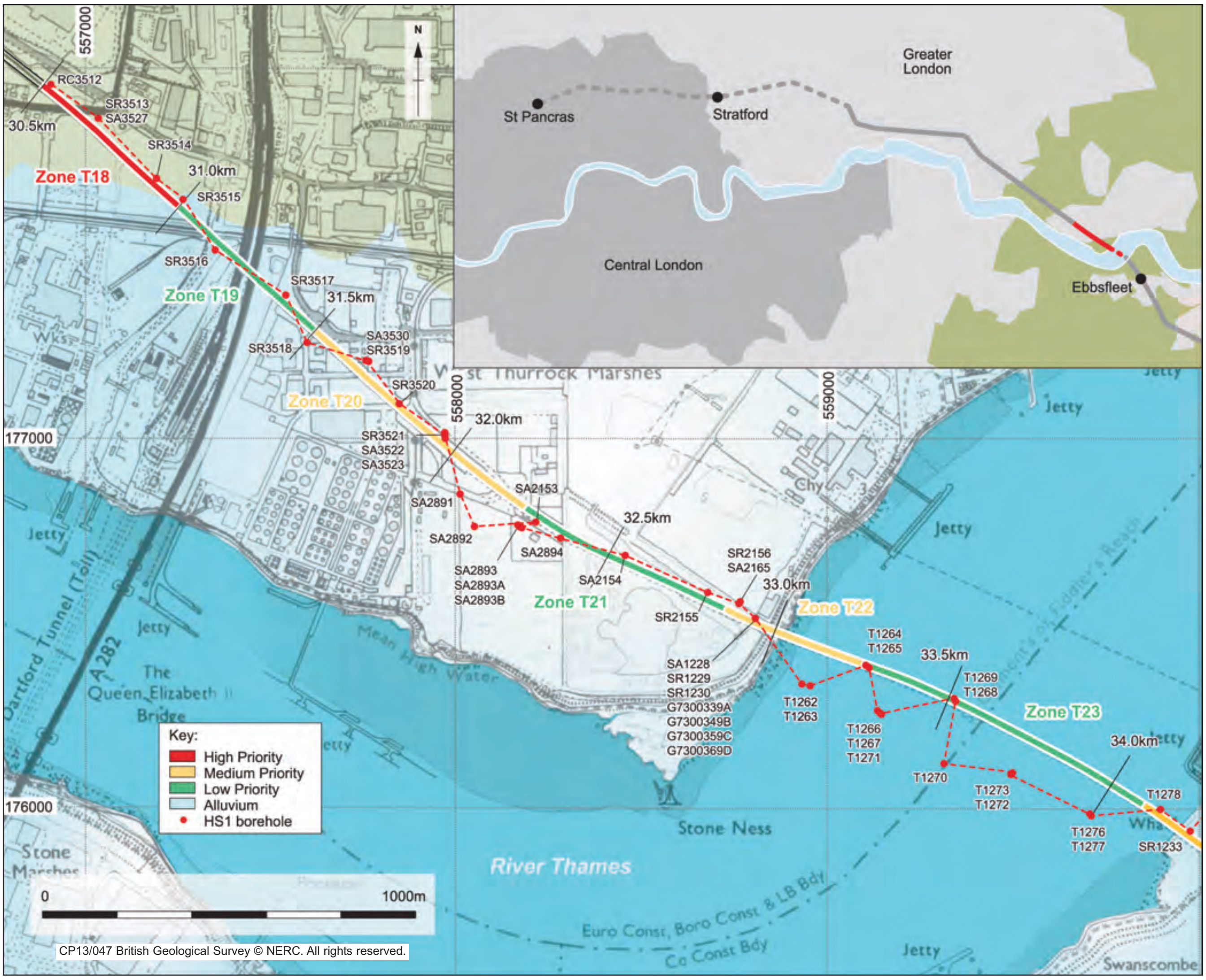

Figure 27 HS1 route corridor Window 11 (Zones T18–T23): location of boreholes

Holocene sediments are complex and include at least two peat units. Thick clay-silts, silts, sands and organic units exist above and below the peat. Made ground is relatively thin along the length of the window. Two geoarchaeological zones were defined in this area (*Table 8*).

The zones present here are complex and influenced strongly by the presence of a Thames tributary valley and remnant older Pleistocene sediments. Zone T16 probably formed an island or promontary within the floodplain remaining dry throughout much of the prehistoric past. Important ecotonal zones surround this area and these may have been a focus for dry ground activity within the rapidly expanding wetland area.

Within the Mar Dyke valley the steeply dipping topography of the Late Pleistocene landscape would have resulted in gradual ecotonal zone shifts through much of the prehistoric period. Dry ground zones around the wetland may have been the focus of considerable human activity.

Window 11: 30.50–33.15km (Thames Crossing)

This section lies between route kilometres 30.50km and 33.15km (Figs 27 and 28). The route corridor lies across the width of the Thames floodplain on the north bank of the Thames.

Bedrock consists of Chalk. The rockhead surface shows some variation in elevation along the window length. Valley edge rockhead datums dip steeply southwards from 30.5km to 31.0km dropping from 9.0m OD to -15.0m OD. Within the main area of the window rockhead datums lie between -13.0m OD and -15.0m OD. The upper surface of the gravels is commonly about -10.0m OD. Holocene sediments are complex and include at least two peat units. Thick clay-silts, silts, sands and organic units exist above and below the peat. Made ground is relatively thin along the length of the window. Six geoarchaeological zones were defined in this area (*Table 8*).

Within this area inundation of the lower portions of the remaining exposed gravel surface would have taken place by about *c* 6000 cal BC (*c* 7200 ^{14}C BP). Within Zone T20 a major, possibly Early Holocene, channel has been noted within or cut into the top of the gravels. Areas associated with the edge of this channel may have considerable archaeological importance.

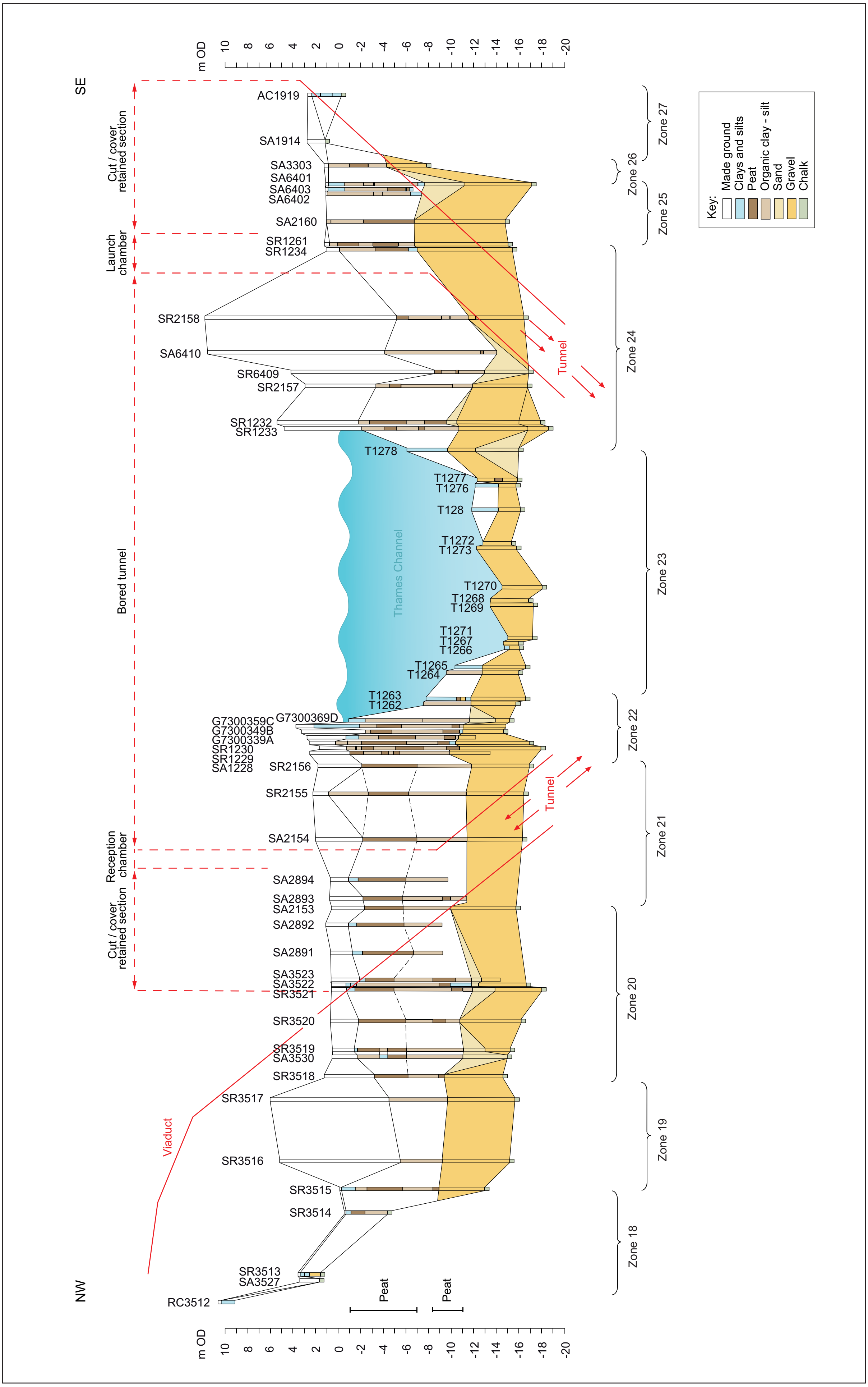

Figure 28 HS1 route corridor Window 11 and 12 (Zones T18–T27): lithological profile

Figure 29 HS1 route corridor Window 12 (Zones T22–T27): location of boreholes

Window 12: 33.15–36.30km (Thames Crossing)
This section lies between route kilometres 33.15km and 36.30km (Figs 28 and 29). The route corridor lies across the width of the Thames floodplain.

Bedrock consists of Chalk. The rockhead surface shows considerable variation in elevation along the window length and ranges from depths of -17.0m OD at the northern end to 0.0m OD at the southern end. Gravel is present beneath much of the route corridor. Holocene sediments are complex and include at least two peat units. Thick clay-silts, silts, sands and organic units exist above and below the peat. Made ground is present along the length of the window.

Five geoarchaeological zones were defined in this area (*Table 8*).

This window is complex and illustrates rapidly changing nature of the preserved sediments between the modern channel and the floodplain edge. Important ecotonal zones are preserved within this region. Initial flooding of the region probably commenced by *c* 6000 cal BC (*c* 7200 ^{14}C BP). A step-like pattern to the Early Holocene topographic template with benches at *c* -7.5m OD, -4.5m OD and 0.0m OD suggest sequential flooding of the south bank may have provided suitable dry ground locations for occupation.

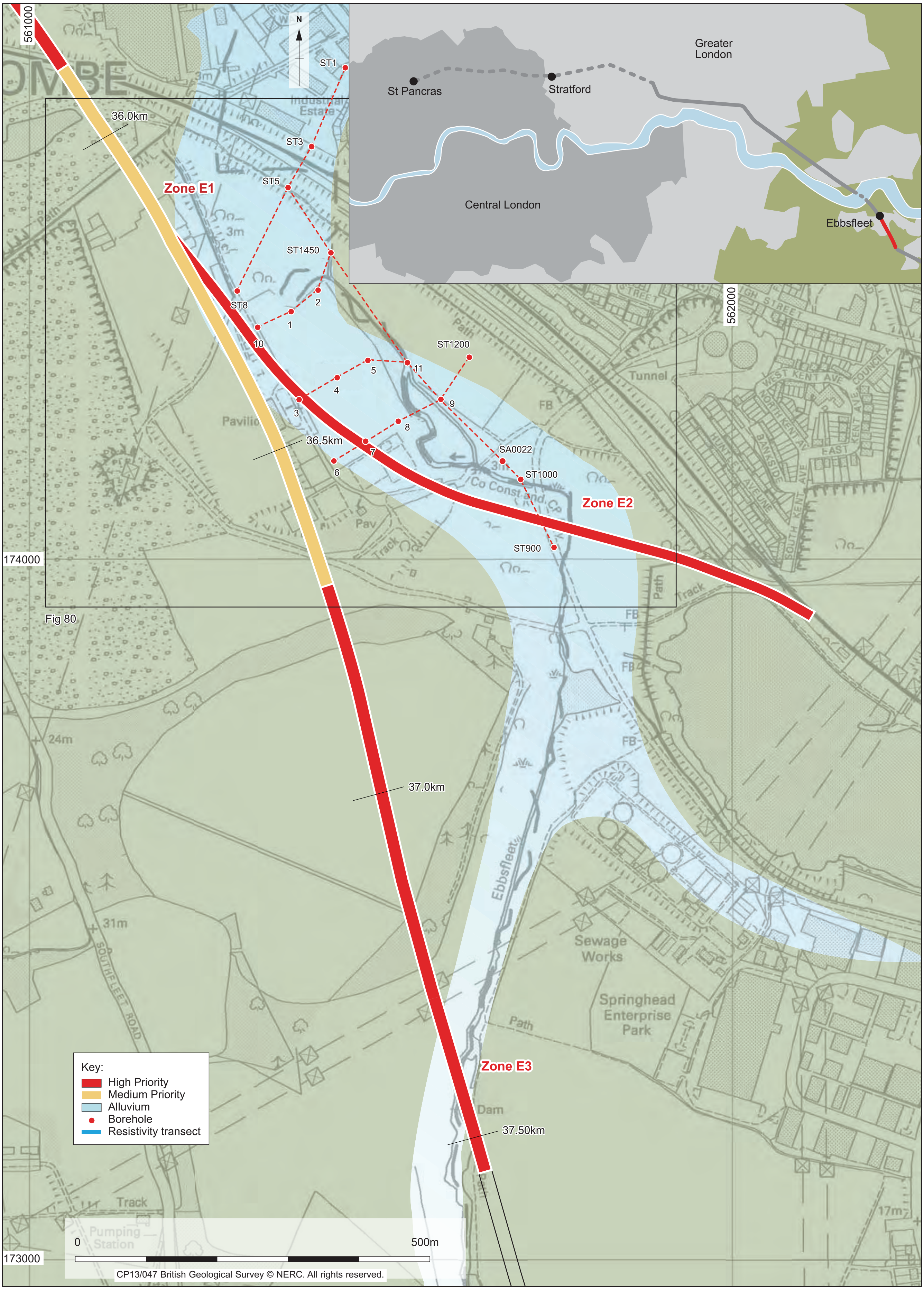

Figure 30 HS1 route corridor Window 13 (Zones E1–E3): location of boreholes

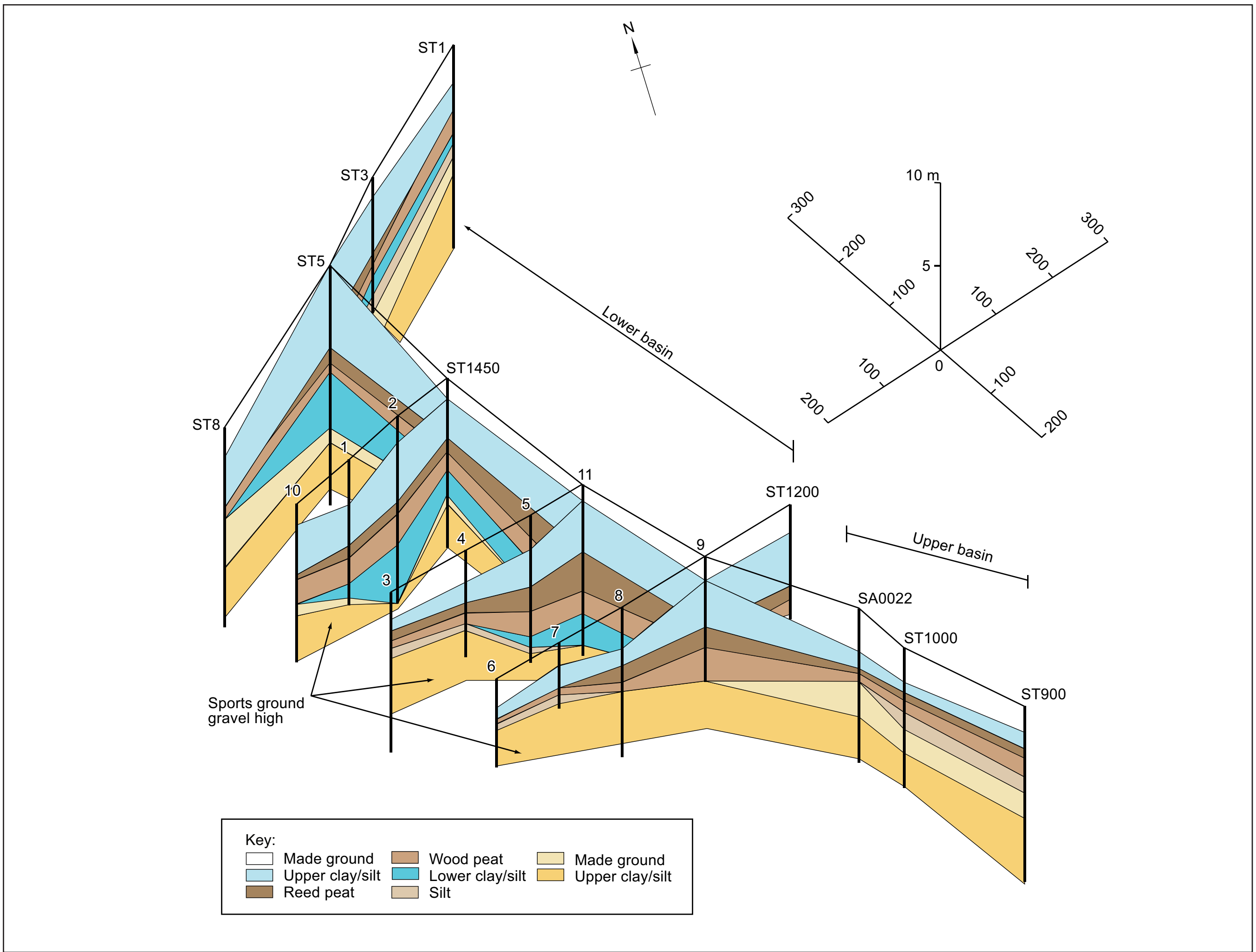

Figure 31 Fence diagram for the alluvial area of the Ebbsfleet Valley Sports Ground complex (Bates and Bates 2000)

Window 13: 35.90–37.55km (Ebbsfleet Valley)
This part of the route corridor lies within the south bank tributary known as the Ebbsfleet Valley (Fig 30). The valley is well known for the Pleistocene sands and gravels present on the valley sides (Wenban-Smith 1995; Oxford Archaeological Unit 1997). Less well known are the rich prehistoric archaeological remains associated with the alluvium in the valley bottom (Burchell 1938; Burchell and Piggott 1939; Sieveking 1960; Barham and Bates 1995; Oxford Archaeological Unit 1995; 1997; URL 1997). These previous works have demonstrated that complex stratigraphies exist in the valley base consisting of clay-silt and organic silts/peats (Fig 31). Towards the valley sides these units probably interdigitate with colluvial sediments derived from the valley margins. The unconsolidated Holocene sediments overlie basal sand and gravel units of probable Late Pleistocene age.

The route of HS1 through the valley consists of the main line running north-west to south-east (Fig 30) along the valley edge area (primarily impacting on the Pleistocene valley side sediments) prior to crossing the River Ebbsfleet 300m south of the sewage works. A major station complex was proposed for the site. A connection with the North Kent Line is made from the southern end of the station complex near South Kent Avenue (Fig 30), crossing the main Ebbsfleet Valley to the east of the Roman building complex (URL 1997).

The Ebbsfleet Valley sedimentary sequence consists of a complex set of deposits showing variable 3-dimensional patterns (Fig 31). Archaeological material contained within these deposits reflects a wide variety of environments of deposition from dry land to tidal mudflats. Important assemblages of artefactual remains from the Neolithic and Roman periods exist in this area. Radiocarbon age estimates suggest initial infilling of the lower parts of the basin prior to *c* 5500 cal BC (*c* 6500 ^{14}C BP), with inundation of the gravel high by *c* 3000 cal BC (*c* 4400 ^{14}C BP).

A Route Specific Geoarchaeological Model for the Study Area

The investigation of the individual route windows defined adequately the nature of the succession in each area and the associated archaeological potential. Specifically it enabled a summarised profile to be drawn up (Fig 7) that illustrated the nature of the sequences along the route corridor. A number of individual features were noted:

- Across much of the western end of the route corridor a two-fold sub-division of the alluvial tract was noted with a shallow basin at the western end of the tract and a deeper basin at the eastern end of the tract;
- The sub-division into two areas indicated that the time depth of the fine grained sediments increased from west to east and the depth to topographic template also increased towards the east;
- A major rise in the topographic template was noted west of the Mar Dyke;
- A buried Pleistocene terrace was noted in the vicinity of the Thames crossing area (south);
- A major peat bed was noted throughout much of the route corridor, although its presence became intermittent towards the west;
- Basal organic sequences were present above the gravel surface across much of the eastern and Thames Crossing areas.

Status and Adequacy of the Data

The mapped status of the alluvium was definitionally relatively poor for a variety of reasons. The BGS mapping is reliable only to a spatial precision of *c* ±50m for edge boundaries. For certain sectors of the route the GMU provided mapping at greater spatial precision. However, the spacing of boreholes is not designed to establish edges to alluvial units and therefore edge definition to better than ±50m (and perhaps even 100m) is unlikely.

It should be remembered that surface 'edge' boundaries mapped for alluvium may shift spatially by 10–100m on gently dipping bed contacts when traced sub-surface, for example, Holocene alluvial overlapping Pleistocene gravels. Surface mapping may be a poor spatial indicator of subsurface deposits, even in shallow superficial sediments. In addition the urbanised and industrial character of the landscape makes mapping boundaries difficult without extensive ground investigation surveys. The borehole data held in the GMU and that subsequently gathered as part of the HS1 project have, however, allowed a refinement to be made in terms of defining edges and boundaries of the alluvium. However, even on completion of the project, the distribution of data along the route corridor remained uneven and skewed to areas of major engineering structures rather than targeting areas of potential archaeological interest.

Methodologies for Field Investigation

Borehole Investigation

Information from boreholes is often available in geotechnical reports (Clayton *et al* 1995) undertaken for a range of site investigation purposes and can provide information suitable for deriving predictions relevant to understanding the 3-D geometry of the buried sediment bodies. It should be remembered, however, that the distribution of borehole data across a given site (as well as the methods and techniques used) is typically dependent on the geological conditions, the type of structure and construction design, and methods to be employed (Bell 1993). Additionally, because such data collection is driven by commercial requirements, it may have only restricted predictive value in geological terms. In such situations, preliminary models derived from engineering boreholes may be usefully supplemented by 'purposive boreholes' during a second phase of drilling investigation.

A range of equipment is available for investigation of sub-surface contexts from unpowered manually driven devices such as Hiller borers and Russian (D-section) corers, which retrieve variably undisturbed sediment cores from soft sediments, to powered mechanical corers with a number of interchangeable coring heads (eg, Eijkelkamp system); small portable drill rigs, including the Terrier 2000 self-propelled drill rig with a windowless liner sampling system; wireline percussive drilling; sonic drilling; and multi-purpose rigs such as the Comacchio system (Bates *et al* 2000a; Clayton *et al* 1995). Selection of appropriate drilling equipment varies dependant on a number of factors including costs, site ground conditions, nature of the overburden, the type of sediment likely to be encountered in the sub-surface and the nature of the samples required for analysis.

Applications of coring and augering methods in archaeology include tracing the lateral extent of near-surface sites as part of cultural resource evaluations (Stein 1991), investigation of deposit depth and composition prior to excavation on middens, mounds and tells (eg, Reed *et al* 1968), the coring of rockshelter deposits (Bailey and Thomas 1987), assisting in reconstructing off-site palaeo-environments (Barham 1999) and understanding the development of urban areas (Densem and Doidge 1979; Ammerman 2000). Coring has also been deployed to assist in mapping archaeologically significant facies environments beneath urban areas, such as tufas in the Lower Dour, Kent (Bates and Barham 1993), and to stratigraphically link excavated sequences into adjacent palaeolandforms and landsurfaces (eg, Barham and Bates 1994). In Europe, coring coupled to excavation trenching, has been used in the study of agricultural systems buried beneath alluvium (Martín-Consuegra *et al* 1998).

Non-archaeological uses include the construction of lithostratigraphic models of Quaternary-age sediment bodies, including Holocene alluvium members and formations (Bridgland 1988; Gibbard 1985; 1994), and the recovery of samples for biostratigraphic analysis, radiocarbon dating and palaeoecological reconstruction of floodplain environments (Devoy 1979). Good examples of the use of large datasets in the construction of sub-surface models include the work of Chen *et al* (1996) on the North China Plain, Berendsen and Stouthamer (2001) in the Rhine-Meuse delta region, Weerts *et al* (2005) in the Netherlands, Culshaw (2005) in Manchester and the Neath/Swansea area of south Wales.

Cone Penetration Testing

The cone penetrometer was developed in the Netherlands in 1934 (Vermeiden 1948) and has gained a wide acceptance within geotechnical engineering for determination of soil properties and stratigraphy. The method is based on the interpretation of the resistance of the tip of the cone rods and friction on the trailing sleeve as the cone is advanced into the ground. The technique is fast, economic and useful for sub-surface sediment characterisation and stratigraphic analysis. It is especially suited to fine-grained sediments (Table 9), however, caution must be given to interpretation of CPT data in coarse sand or gravel, with the latter often causing complete cone rejection.

A typical setup consists of a 20-tonne capacity hydraulic penetrometer mounted in a heavy tracked vehicle ballasted to produce a reaction weight of about 14 tonnes. A 7.5 or 5 tonne capacity electric cone may be selected such as the Fugro piezo-cone penetrometer. In this case the cone has a 60° apex at the tip, a 10 or $15cm^2$ base area and a 150 or $200cm^2$ sleeve surface area combined with pore water pressure element (and resistivity probe). The cones are vertically advanced at a standard rate of 2cm/sec for readings of tip resistance and sleeve friction. Both tip resistance and sleeve friction are related to sediment type and moisture content and the ratio of the tip resistance to the sleeve friction provides information that can be used to classify sediment type (see Chap 11, Fig 66). Pore pressure readings can also be taken during the cone drive. Resistivity of the sediment can be measured using an array of electrodes that record the bulk resistivity of the soil around and between the electrodes. Bulk resistivity represents the total electrical resistance contributed from all sources (grains, matrix material and water) and is a useful downhole check on surface measured ground resistance properties (see below). Output from the cone penetrometer includes curves of tip resistance, sleeve friction, pore content and electrical resistivity with depth.

Examples of the application of CPT data to Quaternary geological/palaeoenvironmental or archaeological projects are limited but it has been used to construct large-scale stratigraphic models of the Po Plain, Italy (Amorosi and Marchi 1999), to produce cross-section data (Howie *et al* 1998) and to locate the presence of buried structures under the Metropolitan Cathedral in Mexico City (Ovando-Shelley and Manzanilla 1997).

Table 9 Sediment classification based on CPT data (based on Clayton *et al* 1995) and approximate ranges of physical properties for some common materials (after Telford *et al* 1990; Reynolds 1997; and Guegiem and Palciauskas 1994)

Sediment type	Cone resistance	Friction ratio	Excess pore pressure	Density	Resistivity
Organic sediments/peat	Low	Very high	Low	1.1–2.4	10–300
Normally consolidated clay	Low	High	High	1.6–2.6	1–80
Sand	High	Low	Zero	1.7–2.3	80–500
Gravel	Very high – refusal	Low	Zero	1.7–2.4	80–500
Chalk	Very high – refusal			1.5–2.6	50–200

Table 10 Electrical properties of selected sediments

Material	Density Mg m^{-3}	P-velocity ms^{-1}	S-velocity ms^{-1}	Resistivity Ohm-m	Magnetic susceptibility
Clay	1.6–2.6	1000–2500	500–1500	1–100	
Silt	1.8–2.2	500–2500	250–1000	10–200	
Sand	1.7–2.3	200–2000	100–1500	50–500	
Peat	1.1–2.4	100–500	100–500	10–300	
Gravel	1.7–2.4	400–2500	200–1500	50–500	
Sandstone	1.6–2.7	1400–5000	800–3000	$10–10^8$	0–21,000
Chalk	1.5–2.6	2000–5000	800–3000	50–150	
Shale	1.7–3.2	2000–4500	800–2500	20–1000	60–18,600
Granite	2.5–2.8	4500–6500	1500–3000	$300–10^6$	10–50,000
Basalt	2.7–3.3	5500–6500	2000–3000	$10–10^7$	500–182,000

Electrical Geophysical Investigation Techniques

Electrical techniques are extensively used in near surface geophysical investigations and include both direct current (DC) resistivity methods and indirect electromagnetic (EM) methods. All electrical techniques induce electrical currents in the ground, which are used to measure the variation in ground conductivity or its inverse resistivity. Different materials (solid rock and drift deposits), and the fluids within them, show different responses to an applied electrical current. In general, sequences with high clay contents show higher conductivity as do saturated sequences, especially sequences where saline waters are present. Conversely sequences with low clay content, sands and gravel or bedrock, such as limestones and chalks, show low conductivity or high resistivity (Table 10). Direct current resistivity is one of the most common methods for field practice relying on directly placing an electrical current into the ground using two electrodes and measuring the response (the electrical potential) to that current over a set distance between two additional electrodes. By combining measurements made at a number of different electrode locations and separations it is possible to construct geo-electric pseudo-sections. These sections can then be interpreted as geologic sequences when correlated with borehole or CPT ground truth data. A number of commercial systems have been designed for the rapid acquisition of 2D pseudo-electrical resistivity sections, including the Lund System (Abem Ltd), Campus Instruments and SYSCAL (Iris Ltd) systems.

Electromagnetic techniques have been extensively developed and adapted over the last 15 years to map lateral and vertical changes in conductivity (Reynolds 1997). Two types of electromagnetic survey are currently practised: i) time domain electromagnetic (TDEM) surveys which are mainly used for depth soundings and more recently in advanced metal detectors, and ii) frequency domain electromagnetic (FDEM) surveys that are used predominantly for mapping lateral changes in conductivity. Both electromagnetic survey types rely on inducing electrical currents in the ground by creating an electromagnetic field in a coil of wire located at the surface. In FDEM, the secondary electric currents are recorded by an additional electrical coil located at the surface. FDEM has proved particularly successful in mapping near surface and surface changes in conductivity because at low electrical induction numbers the ratio of the secondary and primary magnetic fields is linearly proportional to the terrain conductivity (McNeill 1990). FDEM potentially represents one of the most useful geophysical techniques in archaeological investigations as changes in conductivity are often associated with differences between archaeologically significant lithological sequences (see Table 10) and also disturbed ground. Instrumentation exists to survey to a range of depths by using different source and receiver coil separations (see Table 11).

Table 11 Approximate depth of investigation ranges for Geonics Ltd electromagnetic survey instruments

Instrument	EM-38	EM-31	EM-34	EM-34	EM-34
Coil Spacing	1m	3.7m	10m	20m	40m
Horizontal Dipole	0.75m	3m	7.7m	15m	30m
Vertical Dipole	1.5m	6m	15m	30m	60m

Both DC and EM approaches have been successfully used to map lithology, channel-belts and valley fills (Baines *et al* 2002), to study the palaeohydrography and subsurface geology of sites in the Nile Delta (Ibrahim *et al* 2002), and to map Holocene and Pleistocene sediments in the Medway Estuary (Bates *et al* 2007) and in Sussex (Lewis and Roberts 1998; Bates *et al* 2000; Bates and Bates 2000).

Designing the Survey Strategy

Developing a methodology for implementation within projects, either associated with archaeological investigation works or speculative ground investigation for Quaternary research, should be approached on a site by site basis. However, a number of elements may be combined together to facilitate investigation. Desk-based study of extant data sources, particularly records held by national geoscience bodies (Culshaw 2005) or local authorities, often provides substantial quantities of data from previous geotechnical investigations. Design of the field programme will be influenced by both the extant data sets and the project specific aims and objectives. Commonly, a two-step approach to field investigation is recommended, commencing with field trials for the techniques proposed, in order to clarify their suitability as well as to obtain preliminary data sets. This stage will allow appropriate techniques to be selected and provide a first order sub-surface model. The precise timings of works (eg, geophysical survey, borehole drilling) will be dependent on a number of factors, but typically geophysical surveys would be concluded prior to, or during, the final phase of ground truth drilling and sampling. Finally, recovery and laboratory logging of cores, coupled with assessment of the contained microfossils allows initial environments of deposition to be assigned to each sedimentary unit.

The successful design of a mixed method approach to investigation is dependent on the careful construction of the survey methodology, based on the consideration of a number of key geological and practical (finance/accessibility) factors. Key points to consider are:

1. The nature of the geological/geomorphological system. While it is obvious that sequence complexity varies according to the geological systems and local geomorphological constraints, it is important to ensure that an adequate

sampling interval (both vertically and laterally) is adopted that takes into account the likely levels of variation within the system being studied.

2. Field study size area. This is dependent on the perceived nature of the sediments/system being investigated and questions being asked, including the experience of the fieldworker. In commercially driven projects this may be defined by the construction area. However, that may, or may not, make geomorphological sense for understanding the regional context and the broader stratigraphic relationships of deposits.
3. Project aims and objectives and the goals of the project in terms of information required and models being tested. Sampling of a fluvial gravel body, for example, the Boyn Hill Member of the Lower Thames (Bridgland 1994; Gibbard 1994), for either contained archaeological material or gravel clast lithological analysis, requires radically different sampling types and frequency of interventions (many as opposed to one or two respectively).
4. Sequence recovery or sequence logging. The necessity to recover samples for characterisation or undisturbed testing will determine the type of borehole technique used. Sites where it is only necessarily to broadly categorise the underlying sediments and sub-surface topography could be investigated rapidly (and cost-effectively) through the application of geophysical techniques or CPT survey, coupled with occasional ground truth boreholes. If it is important to an individual project to look at the structure of the sediments and sample these for further assessment/analysis (eg, dating) then collection of sleeved borehole samples would be required.
5. Depth of sequences. The depth of burial of the features/deposits of interest is important as different techniques have different investigation ranges (equally applicable to drilling techniques as well as geophysical surveys). With all geophysical techniques the depth range is technique dependent, resulting in a "trade off" between the investigation depth and resolution of the technique with respect to the feature of interest. A technique that will look deep into the earth generally does so with lower resolution compared to a technique designed to investigate shallow depths. With boreholes it is often the case that sample recovery becomes poorer with depth.
6. Target size. An estimation of the target size is necessary prior to selecting appropriate techniques and survey parameters such as the spatial frequency of sampling. The target size should be considered in conjunction with the depth range for individual techniques.
7. Measurement/sampling station interval. This depends on the nature and complexity of the geological system, as well as (for geophysical investigations) the burial depth, target size and techniques selected. In the case of geophysical surveys these have traditionally been conducted along line profiles or on grids, therefore the station spacing along the lines must be calculated together with the line separation in order to not miss a particular target size. Determining locations for boreholes is, in part, dictated by the perceived complexity of the sub-surface geology as well as the nature of the evidence that is necessary to extract from the samples (ie, larger samples and at more frequent intervals will be necessary if project objectives are the recovery of evidence pertaining to human activity (rather than vegetation or water body reconstruction based on pollen or foraminifera respectively).

While many of these points are likely to be very familiar to readers they are rarely discussed in the literature. Considered discussion of the sampling strategies used, their strengths and weaknesses, and the limitations in the study, should form an essential part of the discussion of the project and write-up. Failure to inform the reader and consider such information will make it difficult to address the success or failure of a project. For example, the failure to locate certain deposits or certain classes of palaeoenvironmental data needs to be considered in the light of the methodologies used and systems from which the material came. The dangers of inadequate survey design have recently been discussed by Salvany *et al* (2004) in the Agrio River valley, Spain.