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Manuscript Draft

Manuscript Number: PGEOLA-D-10-00004R1

Title: An enhanced record of MIS 9 environments, geochronology and geoarchaeology: data from construction of the Channel Tunnel rail-link ... Purfleet

Article Type: Research Paper

Keywords: Thames terrace deposits; Palaeolithic; MIS 9 interglacial highstand; geochronology; biostratigraphy

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Abstract: New data from the complex Lower Thames locality at Purfleet, Essex, reinforce the correlation of interglacial deposits there with Marine Isotope Stage (MIS) 9, the second of four post-Anglian (MIS 12) interglacials recorded in the river terrace sequence east of London. Arising from various developer-funded archaeologically-driven projects, and primarily the construction of 'High Speed 1' (HS1: formerly the Channel Tunnel Rail Link), the new evidence includes additions to palaeontological knowledge of this interglacial, notably from ostracods and vertebrates, results from isotopic analyses of shell and concretionary carbonates, and the first application of numerical geochronological techniques at Purfleet. These analyses, combined with mutual climatic modelling of the ostracods, confirm that deposition of the fossilferous deposits coincided with interglacial conditions, with similar-to- or warmer-than-present summer temperatures and colder winters, providing a suggestion of greater continentality. OSL and amino-acid racemisation support correlation of the interglacial with MIS 9, whereas the climatic and sedimentological evidence points to correlation with the earliest and warmest substage (MIS 9e). There is also evidence that a greater part of the Purfleet sequence might date from the interglacial, although whether these also represent MIS 9e or later parts of the complex stage cannot be determined. The additional archaeological material is consistent with previous interpretations of a tripartite stratigraphical sequence of lithic traditions: basal Clactonian, above which is Acheulian (handaxe manufacture), followed by one of the earliest British appearances of Levallois technique.

An enhanced record of MIS 9 environments, geochronology and geoarchaeology: data from construction of the High Speed 1 (London–Channel Tunnel) rail-link and other recent investigations at Purfleet, Essex, UK

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ABSTRACT

New data from the complex Lower Thames locality at Purfleet, Essex, reinforce the correlation of interglacial deposits there with Marine Isotope Stage (MIS) 9, the second of four post-Anglian (MIS 12) interglacials recorded in the river terrace sequence east of London. Arising from various developer-funded archaeologically-driven projects, and primarily the construction of 'High Speed 1' (HS1: formerly the Channel Tunnel Rail Link), the new evidence includes additions to palaeontological knowledge of this interglacial, notably from ostracods and vertebrates, results from isotopic analyses of shell and concretionary carbonates, and the first application of geochronological techniques at Purfleet. These analyses, combined with palaeotemperature estimates from the Mutual Ostracod Temperate Range method, confirm that deposition of the fossilferous deposits coincided with interglacial conditions, with similar-to- or warmer-than-present summer temperatures and colder winters, providing a suggestion of greater continentality. OSL and amino-acid racemisation support correlation of the interglacial with MIS 9, whereas the climatic and sedimentological evidence points to correlation with the earliest and warmest substage (MIS 9e). There is also evidence that a greater part of the Purfleet sequence might date from the interglacial, although whether these also represent MIS 9e or later parts of the complex stage cannot be determined. The additional archaeological material is consistent with previous interpretations of a tripartite stratigraphical sequence of lithic traditions: basal Clactonian, above which is Acheulian (handaxe manufacture), followed by one of the earliest British appearances of Levallois technique. However, given the revised

interpretation of the climatic affinity of the upper parts of the sequence, Levallois technique might have been used at Purfleet before the end of MIS 9.

1. INTRODUCTION

The 100 kyr Milankovitch cycle containing the Marine oxygen Isotope Stage (MIS) 9 interglacial is without doubt the least well researched within the late Middle Pleistocene, given the plethora of data now available from MIS 7 (e.g. Murton et al., 2001; Schreve, 2001, 2004; Schreve and Bridgland, 2002; Bridgland et al., 2003; Desprat et al., 2006; Schreve et al., 2006; Roucoux et al., 2008) and MIS 11 (Droxler et al., 2003; Rousseau, 2003; Antoine and Limondin-Lozouet, 2004; Preece et al., 2007). Thus the Lower Thames terrace sequence at Purfleet (Fig. 1), established with some confidence as representing MIS 10–8 (Bridgland, 1994; Bridgland and Schreve, 2001, 2004; Schreve et al., 2002), would be of considerable importance as a Quaternary fossiliferous locality even without its Palaeolithic archaeological credentials: within the Purfleet sequence, three stratigraphically discrete Palaeolithic industries have been documented, Clactonian, overlain by Acheulian, overlain in turn by Levallois (Palmer, 1975; Wymer, 1985, 1999; Bridgland, 1994, 2006; Schreve et al., 2002). Indeed, the Purfleet sequence has been used as a pinning point for the first appearance of Levallois in Britain (Bridgland, 1994, 2006; White and Ashton, 2003; cf. Westaway et al., 2006).

The Lower Thames (between central London and the estuary) is of unique importance within north-west Europe for its extraordinarily complete sequence encompassing the last four climate cycles (Bridgland, 1994; Schreve, 2001). Chalk bedrock, brought to the surface by the Purfleet Anticline, has provided both groundwater conditions suitable for preserving calcareous fossils and, in nodules and bands, the flint raw material for Palaeolithic tool-making, ensuring that the terrace sequence here provides a record of human activity and environmental changes over the last ~450,000 years. The Lower Thames is home to internationally important sites of longer standing than Purfleet, such as the Swanscombe human-fossil site (Ovey, 1964; Conway et al., 1996), representative of MIS 11, and the Aveley elephant site (Sutcliffe, 1966; Schreve et al., forthcoming), which records a complex MIS 7 sequence. These and other key sites (cf. Bridgland, 1994) combine to provide one of the most complete terrestrial records of the last 0.5 Ma anywhere and form the regional context for the Purfleet locality (Figs 2 and 3). This combines with earlier data from sites at Grays and Little Thurrock (Hinton and Kennard, 1900; West, 1969; Bridgland, 1994), within the same terrace, to provide the MIS 10–8 component of this record, added to which are correlative sites upstream at Hackney, in East London (Green et al., 2006), Upminster, Essex (Ward, 1984), and downstream at Barling (Bridgland et al., 2001) and Shoeburyness (Roe et al., in press), near Southend-on-Sea, Essex. Even closer to Purfleet, a locality with interglacial sediments and Palaeolithic artefacts that came to light during construction of the M25 motorway, at Belhus Park, Aveley (Fig. 2), has been attributed to the same MIS 10–8 Thames sequence (Bridgland, 1994; Schreve et al., 2002).

The Purfleet area has seen a plethora of recent developments, amongst which the construction of ‘High Speed 1’ (HS1: formerly the Channel Tunnel Rail Link: CTRL), which cuts through the Purfleet outcrops (Fig. 1), is perhaps the most significant. It led to a programme of developer-funded multi-disciplinary research that has uncovered new evidence from the Purfleet sequence and has allowed the application of new techniques to these deposits, as will be reported here.

1.1 Previous research at Purfleet

Large areas bordering the Lower Thames were subjected to extensive quarrying throughout the 19th and 20th centuries but the Pleistocene deposits at Purfleet were revealed only by gravel and Chalk extraction in the 1960s and 1970s, in quarries either side of the Purfleet Bypass (Bluelands, Greenlands, Esso and Botany pits, in north-east–south-west sequence; Fig. 1). Archaeological excavations were conducted by Palmer (1975) and A. Snelling (in Wymer, 1968, 1985), from which the tripartite Palaeolithic sequence was first established (Wymer, 1985). Hollin (1971, 1977) studied the sediments and identified the temperate-climate origin of parts of the sequence, attributing them to the last (Ipswichian Stage) interglacial, which would now be correlated with MIS 5e. He also noted that the sedimentology of one of the interglacial beds suggested an estuarine origin. The combination of the rich Palaeolithic heritage and geological evidence at Purfleet led to designation as a Site of Special Scientific Interest (SSSI) by the Geological Conservation Review in the early 1980s (Bridgland, 1994; Fig. 1). In many of the earlier reports the deposits were attributed to the Mar Dyke, a minor Thames tributary (Fig. 2), although Bridgland (1994) refuted this, showing that they form part of a z-shaped loop of the Lynch Hill/Corbets Tey terrace of the Thames, as predicted by observations (before the exposures at Purfleet were created) by Wooldridge and Linton (1955).

A significant independent appraisal of the Purfleet deposits took place in the mid-1990s, centred around section cleaning in Greenlands Quarry. This involved detailed analyses of molluscan and vertebrate faunas and led to confirmation of the earlier suggestion, based on the river terrace stratigraphy (Bridgland, 1994), that the interglacial at Purfleet represents MIS 9 (Schreve et al., 2002). Despite involving minimal disturbance of the sediments, this work produced a small quantity of additional stratified archaeological material, within which there was nothing to contradict the tripartite sequence advocated by Wymer. White and Schreve (2000) cited the superposition of Acheulian above Clactonian assemblages at Purfleet as evidence for sequential immigration of different tool-making communities at the beginning of the MIS 9 interglacial, repeating the sequence that can be observed in the higher Boyn Hill/Orsett Heath terrace, representing the early part of MIS 11. The present paper builds on the previous studies, combining new data from a wider area, including the HS1 sections and other recent developer-funded work at and around Purfleet, supplemented by optically stimulated luminescence (OSL) and amino acid racemization (AAR) dating.

2. THE HS1 PROJECT (See Appendix I, online supplement, for full specifications)

The HS1 route runs through a ~30 m wide cutting parallel with and immediately south of the Purfleet Bypass (Fig. 1). The evaluation and recording of the deposits at Purfleet in advance of HS1 construction involved both the Oxford and Wessex Archaeology units, aided by numerous specialist consultants. This was a phased project, designed to obtain additional sedimentological and palaeoenvironmental data as well as collecting archaeological material under controlled conditions. Following initial appraisal of pre-existing and newly-obtained borehole evidence, four test pits were excavated (2001–2004 TP; Fig. 1) to assess the potential survival of archaeological and environmental material, to evaluate the likely impact of railway construction on the Pleistocene deposits and to contribute towards formulating a scheme of work to mitigate the effects of construction (Project code ARC THPE 94 (URL, 1995)). These preliminary test pits were positioned primarily to examine deposits adjacent to the edge of the Thames sediments, where they abut the bedrock chalk, in which situation it was considered that archaeological material would be optimally preserved. These excavations recovered Palaeolithic artefacts from thin deposits cryoturbated into the top of the Chalk (2004TP), as well as discovering fine-grained pollen-bearing sediments in this high-level feather-edge situation (R. Scaife, in Bates et al., 1999). The results of this first phase were used to design a more detailed investigation (Project code ARC PFC 01 (URL, 2002)), involving the excavation of six large trenches along the line of the proposed railway (3953TT–3957TT and 3982TT: Fig. 1; see online supplement, Appendix I) during which sections were cleaned, recorded and sampled for the analysis of gravel clast lithologies, molluscs, vertebrates, plant macrofossils and/or pollen. These investigations, during which interglacial laminated and fossiliferous deposits (previously known only from Greenlands and Bluelands quarries) were discovered on the south-west side of the Purfleet Bypass, provided a well-documented control for the final phase of work, which was a watching brief (Project code ARC 310T 02) during HS1 construction. This phase, which provided extensive sections that were logged, photographed and surveyed as they were excavated, allowed the sediment geometry over the whole site and the linkage between the original test pit sections to be established (Fig. 4). The overall project methodology placed emphasis on recovering data from vertical sections and made no contingency for analysing artefacts and spatial patterns from area excavation. In synthesizing the results, information has been incorporated from other small-scale evaluation work and rescue excavations in the Purfleet deposits, as will be documented below. The data have been evaluated in the context of the previous detailed report on the Purfleet deposits by Schreve et al. (2002), using their stratigraphy as a framework.

3. LITHOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE CORBETS TEY FORMATION AT PURFLEET

The Pleistocene sequence at Purfleet has been summarized previously by Hollin (1977), Bridgland (1994) and Schreve et al. (2002). The stratigraphy from the HS1 sections (Figs 4, 5 and 6) is expanded from the last-mentioned, using their bed-numbering scheme. In particular, there are newly recognized elements within the high-level valley-side edge of the terrace at the south-eastern end of the site (see Figs 1 and 4). The full sequence, with new units added, is now as follows (bold text signifies formal lithostratigraphical nomenclature).

9 Overburden. Homogenized sands, silts and (generally subordinate) clay; incorporates possible loessic cover and/or colluvium. The uppermost fluvial beds may also have been homogenized by periglacial and pedogenic processes.

8iii Uppermost gravel, only distinguishable from the main body of Bed 8 where it overlies Beds 8i and 8ii.

8ii Laminated silt and clay. Recorded only near the extreme south-eastern limit of the Pleistocene section in the HS1 cutting, in particular in Trenches 2001TP and 3957TT (see below), this is the deposit recorded by Bates et al. (1999) from which pollen was obtained.

8i Bedded sand. Restricted to the south-eastern half of the HS1 alignment, this sand is horizontally bedded in the north-west (in 3956TT) and cross bedded in the south-east (in 3982TT), where it thickens markedly (Fig. 4).

8 **Botany Gravel** Cold-stage gravel, sands and silts deposited in a braided stream and forming part of the Corbets Tey Upper Gravel, which has been equated with MIS 8 (303,000–245,000 BP). It contains Levallois artefacts. In the absence of Bed 7 across most of the site (below), this bed cannot readily be distinguished from Bed 6.

7 Decalcified clay/silt. Sedimentology is suggestive of a warm-climate water-lain origin (cf. Schreve et al., 2002). Seen only in the north side of Greenland quarry (see below, Armor Road extension) and in the Esso Sport Field boreholes (see below) and not encountered in the main HS1 project area.

6 **Bluelands Gravel.** This gravel is associated with Acheulian archaeology but is generally unfossiliferous, although this may result from post-depositional weathering, since it generally lies above the decalcification front (cf. Schreve et al., 2002). Its interglacial or post-interglacial origin is uncertain, therefore. In the absence of the overlying Bed 7 it is difficult to differentiate this deposit from Bed 8.

5 **Greenlands Shell Bed.** A shell-bank deposit, identified in Bluelands and Greenlands Pits, representing fully interglacial freshwater conditions. This bed was not encountered in the main HS1 project sections, although it is well represented in the Greenlands Quarry west face, the Armor Road extension section and beneath the Esso Sport Field.

4 Laminated sand, silt and clay (interglacial estuarine deposit). This bed, which is locally fossiliferous in the northern part of the SSSI, was traced in HS1 trenches into Botany Pit. Particle-size analysis as part of the HS1 project shows that its finer-grained laminae are dominantly silt (see below and Appendix II, online supplement).

3 Shelly gravel. Interglacial sandy gravel with chalk, molluscs and Clactonian artefacts that rests on the basal cold-climate gravel or, in some areas, directly on brecciated chalk. Where decalcified and lacking fossils, this bed is easily confused with Bed 2. In the HS1 sections (3953TT and ARC 310 T02) it was recorded for the first time south of the Purfleet Bypass, beneath the floor of the erstwhile Botany Pit.

2 **Little Thurrock Gravel.** Basal cold-climate gravel, discontinuous. Contains Clactonian artefacts. Records the latter part of MIS 10.

1 Coombe-rock (soliflucted and brecciated chalk)

0 Chalk bedrock

3.1 Sections and Evaluation Trenches (described in more detail in Appendix II)

ARC 361 00 (Section 108: Fig. 6)

This was the most important record from the north-western part of the site (Fig. 6), where only the lowest parts of the Purfleet sequence survive. Fossiliferous gravel (Bed 3) overlay the Chalk directly (there being no evidence for a pre-interglacial gravel) beneath ~1.4 m of laminated silts (Bed 4), both units providing valuable palaeoenvironmental and biostratigraphical data (see below).

Trench 3957TT (Fig. 7)

The southern part of this trench revealed involutions and solution features (Fig. 7) filled with silts and sands with gravel, including flint artefacts (identical to the above-mentioned finds from 2004TP). The deposits form the feather-edge of the Corbets Tey Terrace at Purfleet, resembling those recorded in a similar situation in Greenlands Quarry to the north. The lowest bed is a poorly sorted clast-supported sandy gravel, declining northwards from ~16 m O.D. and forming the feather-edge of a fluvially deposited gravel, probably the Botany Gravel, although there can be no certainty that it is not the Bluelands Gravel (see above; cf. Fig. 4). It was overlain by climbing-ripple laminated sands, silts and clays, with foresets indicating a west to south-west palaeoflow direction (in keeping with location within the ‘z’-shaped Corbets Tey palaeovalley – see Fig. 2). This is the enigmatic polleniferous Bed 8ii seen previously in 2001TP (see above), which was located immediately adjacent to 3957TT (Figs 1 and 7). The sequence was completed by fluvially bedded, matrix-supported gravel (Bed 8iii) and poorly bedded brown/yellow–brown sandy silt (overburden), which also filled the solution features (Fig. 7; see also Appendix II, online supplement). The stratigraphical relations of Beds 6, 8 and 8ii will be discussed further, below.

Trench 3982TT (Fig. 8)

This trench, 45 m north-west of 3957TT, was positioned with the intention of revealing the feather-edge sequence targeted in that trench but not fully exposed. Although the 3982TT section provided a more complete record of the deposits represented in 3957TT, it also failed to fully expose the chalk edge. The base of the section was defined by a gently undulating chalk surface that descended from ~15 m to 13.8 m O.D. (south to north). Above this was a coarse, matrix-supported basal gravel, up to 0.4 m thick, feathering to the south (Fig. 8). Containing large numbers of Palaeolithic flakes and cores, was undoubtedly the same deposit as seen in 3957TT, probably also corresponding with the artefact-bearing basal Botany Gravel (Bed 8) in the south-west corner of Greenlands Quarry (see below) and the original source of the Levallois artefacts in Botany Pit (Wymer, 1968). However, the impossibility of distinguishing the Bluelands and Botany Gravels means that it is classified as Bed 6/8 (Fig. 8). It was overlain by cross-bedded sands and silts, with subordinate ripple-drift lamination, indicative of palaeoflow to the south-west (Fig. 8). This deposit, identified in the preliminary boreholes, is part of a substantial sand body (Bed 8i) either within or overlying the Botany Gravel in this part of the HS1 site (Fig. 4) and recorded in previous descriptions of Botany Pit (Podmore, 1976; Shephard, 1976; Lonsdale, 1978) and the Esso Pit (Bridgland, 1994, figure 4.19; see below).

The upper parts of the section were characterized by undulating beds of cross-bedded, moderately sorted medium–fine pebbly, sandy gravel, which have truncated the upper parts of the cross-bedded sand. This was a further representation of the newly defined Bed 8iii uppermost gravel. The sequence was capped by homogenized brown sandy silt overburden. Poorly developed cryoturbation structures were present at the north end of the section, near the interface between the upper gravel and the overburden.

Trench 3956TT (Fig. 9)

This next trench to the north-west revealed a series of horizontally bedded, well-sorted medium–coarse flinty, sandy gravels, in total ~0.8 m thick (Bed 6/8, as before), lying on a chalk bench at approximately 11.5 m O.D. Cross-bedded sands at the base of the sequence confirm a generally south-westward palaeoflow (Fig. 9). The sequences fines upwards into yellow wavy-bedded sand, approximately 0.55 m thick, with gravel stringers and traces of ripple-lamination: a further representation of Bed 8i (see above), its upper part disrupted by poorly developed involutions. The sequence was capped by ?cryoturbated, compact, homogenized silty sand overburden, dark orange-brown and up to 1.8 m thick. The bedded gravel was heavily disturbed at the north end of the trench by solution features, including a ‘pipe’, filled with unbedded dark brown sandy silt, that extended the full depth of the excavation. An approximately east–west aligned ice-wedge cast, well-developed at the south end of the trench (Fig. 9), was also filled with homogenized silty sand, a clear indication that the wedge formed after deposition of Bed 8i.

Trench 3955TT (Fig. 10)

This trench was situated immediately east of the erstwhile Botany Pit, north-west of 3956TT and therefore further from the valley-side edge of the former Thames floodplain. It showed heavily brecciated chalk overlain by bedded gravel, the former disrupted by well-developed involutions filled with manganese-impregnated gravel and covered by a lobe of chalky ‘coombe rock’, thickening eastwards and rising to near the present ground surface. This was associated with a second horizon of involutions. It was in turn overlain, at ~10.6 m O.D., by horizontally bedded medium–fine sandy gravel. Much of the bedding at the north end was heavily deformed by solution collapse. The gravel was sealed by dark red–brown sand interpreted as made ground, such as is present throughout the western end of the transect (Fig. 4), perhaps related to former quarrying (Botany Pit). The fluvial deposits in this trench, heavily cryoturbated at the base and truncated upwards by quarrying, are classified as Bluelands/Botany Gravel (Bed 6/8). It is notable that a similarly disturbed chalk and basal gravel contact was recorded in the nearby north-east corner of Botany Pit (A.J. Snelling, pers. comm.; cf. Wymer, 1968).

Trench 3954TT (Fig. 11)

Situated ~155 m north-west of 3955TT, this trench, restricted in extent by buried utilities, exposured a sequence similar to that in 3953TT. The basal bed, which comprised 0.4 m of coarse–medium sandy gravel, rested on a slightly undulating chalk platform at ~5.9 m O.D. It was overlain by 0.5 m of laminated silt with fine sandy interbeds and dark red–brown silty sand, clearly representative of (estuarine) Bed 4 (see above). Two indeterminate mammalian bone fragments were found in the basal gravel, closely associated with Clactonian artefacts. This suggests that part, at least, of this deposit might be a poor representation of the Shelly Gravel (Bed 3) but in the absence of more definitive fossils, it is tentatively classified as pre-interglacial Bed 2. The presence of the fossiliferous gravel in the vicinity of this trench, in an area badly affected by Chalk solution (Fig. 4), cannot be confirmed.

An upper matrix-supported pebbly gravel overlay the laminated bed at ~7.20 m O.D., its bedding somewhat deformed at the margins of a penetrating solution feature (Fig. 11). This upper gravel might incorporate elements of both the Bluelands and Botany Gravels and is thus classified as Bed 6/8 (Fig. 4). It was capped on one side of the trench by orange–brown silty sand containing irregular pockets of soft yellow sand. It is likely that this unit represents the homogenized overburden with cryoturbation structures seen in other sections (Figs. 4, 5, and 7–9); elsewhere the uppermost deposits were replaced by ‘made ground’.

Trench 3953TT (Fig. 12)

This, the westernmost trench, was 172 m north-west of 3954TT, to the north of the former Botany Pit. The lowermost deposit, overlying chalk at ~6 m O.D. at its lowest point, was a well-bedded, medium–coarse sandy gravel, up to 0.4 m thick. Severely disturbed by solution in the central part of the section, this basal gravel (Bed 2) was overlain by calcareous sand containing calcium-carbonate concretions, often with shells at their centres (identified below as oncoids), highly characteristic of the basal part of the Purfleet interglacial sequence (Schreve et al., 2002). It is thus attributable to Bed 3.

The interglacial sequence continued with a series of laminated silts with fine sand interbeds, increasing in frequency upwards, representing Bed 4. This unit is severely deformed hereabouts, with both folding and small-scale faulting (Fig. 12), probably as a result of collapse into a chalk-solution feature. The upper part of the sequence here was truncated, although clean pebbly sand and gravel was present on the west side of the trench and also filled solution pockets in the laminated beds, suggesting that an upper gravel unit, presumably the Bluelands or the Botany Gravel (Bed 6/8), once capped the sequence.

3.2 Other HS1 sections

McKellar's Section: ARC 3962SE (Fig. 13)

Section 3962SE cut through gravel-filled solution 'pipes' and chalky involutions in the side of an excavation into the base of the McKellar's Yard quarry, now an industrial estate. The area had been stripped of its uppermost stratigrapy by quarrying and the remaining Pleistocene sequence was much disturbed by the combination of cryoturbation and chalk solution; there has also been homogenization and/or solifluction of chalky material mixed with gravel (perhaps including Palaeogene as well as Pleistocene material), forming 'coombe-rock' (Fig. 13). The involutions and solution pipes were generally filled with gravel of clear Thames affinity, from which a few artefacts were obtained, including a proto-Levallois core (see below). It was presumed from the location of the section that this was the Bluelands or Botany Gravel (Bed 6/8), it having overlapped the lower parts of the sequence onto the chalk valleyside (see Fig. 4 [the position of the McKellar's Section relative to the valleyside is comparable to 5955TT]); indeed, a considerable volume of such gravel has been quarried from this and the adjacent Botany Pit.

HS1 cutting watching brief (ARC 310 T02)

During excavation of the new railway cutting (Fig. 1) a 'watching brief' was undertaken, which included recording of the main sedimentary units (using laser surveying equipment) and the production of a photo-archive, as well as retrieval of artefacts and sampling for fossils (see below). The data thus collected has been used to produce Figure 4, which is a section through the Purfleet terrace deposits along the HS1 alignment (and therefore oblique to the former floodplain edge). This revealed deposits not seen in the Greenlands and Bluelands quarry sections recorded by Schreve et al. (2002). As Fig. 4 confirms, the lower parts of the sequence, including the main fossiliferous levels (Beds 3–4) and the underlying pre-interglacial Little Thurrock Gravel (Bed 2), were found only at the north-western end of the cutting, as anticipated from their previous occurrence in only 3953TT and 3954TT. Just to the south-east of 3954TT, Beds 2–4 had been cut out by apparent erosion preceding the emplacement of a widespread gravel, although this part of the section has been greatly affected by solution of the underlying chalk, which has also been subjected to loading and injected upwards by diapirism (Fig. 5). This gravel is classified as Bed 6/8, as before. The implied erosion event would also potentially explain the absence of the lower divisions of the Purfleet sequence in the McKellar's section, where there is again considerable evidence of solution. Indeed, the absence of the less pervious clayey silt of Bed 4 from above the Chalk bedrock may have led to the concentration of solution at these locations.

The south-easternmost two thirds of the HS1 cutting exposed only the Bed 6/8 gravel and younger deposits; the latter, as noted above, compried three additional beds, designated 8i, 8ii and 8iii, a notation that implies a close relationship with the Botany Gravel (Bed 8). Bed 8i is a substantial body of sand, horizontally bedded when encountered in 3956TT but much thicker and cross bedded in 3982TT. The lateral continuity between these trenches was confirmed in watching-brief records (Fig. 4). The extent to which this is a separate sedimentary unit or merely a sandier upper division of Bed 6/8 was difficult to determine, although there are records of sand of various types (horizontally bedded, ripple laminated and cross bedded) interbedded with gravel in both Botany Pit (see above) and in the Esso Pit (Bridgland, 1994, figure 4.19). All these deposits are at very similar heights and may well be lateral equivalents of the sequence in 3982TT), which was only ~0.1 km from the former east face of Botany Pit (Fig. 1). It should also be noted that the low-level Bed 6/8 gravel south-east of 3954TT incorporates an uppermost sand division, not separately designated (Fig. 5).

Less easily interpreted is Bed 8ii, a laminated sandy, clayey silt (see Appendix II, online supplement, for particle-size analysis) that was encountered in 3957TT and in the watching brief immediately to the north-west. This is undoubtedly the deposit from which R. Scaife (in Bates et al., 1999) obtained pollen, from 2001TP; see above and Fig. 1). Unfortunately the relation between this deposit and Bed 8i, which was observed in the watching brief between 3957TT and 3982TT, was unclear; although sand was recorded immediately beneath Bed 8ii in the cutting north-west of 3957TT, it could not be determined whether this was continuous with Bed 8i (cf. Fig. 4). This is of considerable significance, since it means that the relation of Bed 8ii to the Botany Gravel and to other beds within the Purfleet sequence is also equivocal. It remains possible, indeed, that Bed 8ii is part of the same deposit recorded in the north face of Greenlands Quarry and classified as Bed 7 by Schreve et al. (2002). These two highly localized remnants are separated by ~4–5 m vertically (Bed 7 is at ~12.5 m O.D. in Greenlands Quarry) and 0.6 km laterally. If Beds 7 and 8ii are one and the same, then this would confirm (given the palynology) that the Bluelands Gravel and Bed 7 are part of the MIS 9 interglacial sequence and would indicate that the lower part of what has been classified as Bed 6/8 gravel in the HS1 is in fact Bluelands Gravel (Bed 6).

The sediments of Bed 8ii were sampled in Monolith 5791 (from 3957TT) and scrutinized as part of an abortive search for microfossils (although see below, palaeobotany). Like Bed 4, they are ferruginous laminated clays, the abundant iron being attributable to weathering. Unlike Bed 4, they contain no mica, which may indicate a different sediment provenance (mica can be derived from the London Clay). Several of the studied levels also contained tubes formed around rootlets, as well as plant-stem impressions. Poor-quality fossils of this type are common in Pleistocene estuarine sediments and are often all that remains of any palaeontological content. Their presence might thus provide a further clue that this localized bed (8ii) is a further remnant of MIS 9 sediment at Purfleet. In the earlier report on Greenlands and Bluelands quarries, Schreve et al. (2002) pondered whether Bed 7 might represent a later high-sea-level phase within the interglacial, just as is envisaged here on the basis of Bed 8ii. They noted ghosted laminae in Bed 7, hinting at an intertidal mode of deposition, although, given the localized and lenticular disposition of that bed they were unable to rule out other depositional mechanisms. The evidence from Bed 8ii, particularly the tantalizing palynological record (see below), strengthens the suggestion for a more complex interglacial marine highstand record at Purfleet, although there is at present insufficient data to extend this argument further.

The fluvial sequence is completed by an uppermost gravel, Bed 8iii, encountered in 3957TT and 3982TT and in the watching brief in their near vicinity (Fig. 4). In 3957TT this uppermost gravel can be shown to overlie Bed 8ii and so to be the youngest element of the HS1 sequence, although if Bed 8ii and Bed 7 are lateral equivalents then 8iii would merely be a further representation of the Botany Gravel, previously regarded as the youngest element of the Corbets Tey Formation (Bridgland, 1994; Schreve et al., 2002). Given the disposition of the sediments along the HS1 cutting, this might indicate that the lower part of the gravel formerly exposed in Botany Pit was in fact Bluelands Gravel.

3.3 Data from other recent investigations of the Purfleet deposits

In addition to HS1, there have been several recent developments that have provided new data on the Purfleet deposits (Table 1). In 1993 there was an investigation prior to the construction of a warehouse on unexcavated land west of Stonehouse Lane, south of Bluelands and north-east of Greenlands Quarry (Bridgland et al., 1995; Fig. 1). Machine-dug trenches revealed the feather-edge of the Corbets Tey Formation, from which was obtained abundant molluscan remains, ostracod valves, occasional charcoal fragments, and micro-debitage from flint-knapping. The small-mammal assemblage included a number of biostratigraphically important species; Parfitt (in Bridgland et al., 1995) noted that the morphology of the water-vole molars suggested a pre-Ipswichian age and that the shrew fauna resembled that from Grays (Orsett Road), another site in the Lynch Hill Corbets Tey Formation, ~6 km east of Purfleet (Fig. 2). The small vertebrate remains assisted with reconstruction the contemporaneous environment, with woodland and thermophilous mammals indicating fully temperate (interglacial) conditions, the assemblage pointing to a range of habitats, including riparian, woodland and grassland elements. The fish material, probably in primary context, was dominated by species (e.g. members of the carp family) that prefer slow-flowing rivers with high summer temperature and low levels of dissolved oxygen.

This small-scale excavation was a prelude to the re-excavation of sections in the north face of Greenlands Quarry, followed by the detailed appraisal of the interglacial sequence there and on the opposite side of North Road, in Bluelands Quarry, documented by Schreve et al. (2002). The rediscovery during this enterprise of the highly fossiliferous Greenlands Shell Bed led to the extension of these sections for research purposes (Schreve et al., 2002). While that work was being prepared for publication, an extension of Armor Road was constructed through this northern face of Greenlands Quarry (Fig. 1), preceded by archaeological and geological investigations (see below). The floor of Greenlands Quarry was subsequently developed as a warehouse complex, involving the construction of an access ramp that covers much of its former western face. A developer-funded recording and sampling exercise prior to the development confirmed the value of this face as a record of the Purfleet sequence (see below). Bluelands Quarry remains undeveloped, despite a number of putative proposals over the years. Finally, the unexcavated sports-ground site immediately west of the now-buried Greenlands west face has been developed for housing, prior to which a borehole assessment, documented below, was undertaken.

In addition to these developments in and immediately around the Purfleet SSSI, construction of the new A13 dual-carriageway road provided further temporary exposures in fossiliferous Corbets Tey deposits, particularly in the abutments for an overbridge for Ship Lane (Fig. 1), ~1 km to the north of the sections at Greenlands Quarry (see below).

Armor Road extension (Fig. 14)

Work here took place in 1998–1999, prior to the construction of the above-mentioned road cutting. A section in the north face of Greenlands Quarry on the line of the new road was cleaned and recorded (Fig. 14). In addition, there was an area excavation of the uppermost deposits, which were to be removed during excavation of the road cutting. The sequence here matches closely that reported by Schreve et al. (2002) 25 m to the east, with each of their numbered units identified (Fig. 14). The two principal fossiliferous levels, the shelly gravel (Bed 3) and the Greenlands Shell Bed (Bed 5), were well represented. The enigmatic upper silty bed (Bed 7) was particularly well developed, being up to 2 m thick, its basal 0.5 m comprising rhythmically bedded sand, silt and clay (Fig. 14), within which nine clear couplets could be seen, with higher ones destroyed by loading (for full details, see Appendix II, online supplement). The area excavation was confined to the uppermost fluviatile bed, the Botany Gravel (Bed 8), and overlying horizons of soil and made ground (Fig. 14); the gravel was removed to reveal the the irregular top of Bed 7 (a small sondage penetrated this by 0.3 m to confirm the stratigraphy).

Greenlands Quarry, west face (Fig. 15)

Sections at the western end of Greenlands Quarry were cleaned, sampled and recorded during September–November 2001. Important new artefact discoveries were made at several points and the sections also yielded molluscan and mammalian specimens. The recorded section (Fig. 15) revealed a sequence that is readily compared with the definitive Schreve et al. (2002) stratigraphy from ~0.5 km to the east-north-east. A basal unfossiliferous gravel (Bed 2) was well defined, overlain by shelly gravel with calcareous concretions (Bed 3) and then the familiar laminated Bed 4. The last-mentioned was ~3.5 m thick towards the northern end of the section, thinning to the south but also bifurcating at various points southwards, thus showing a degree of interbedding with Beds 3 and 5 (Fig. 15) that had not been apparent in the sections to the north-east. Additionally, lobes of chalky gravel, restricted to this valleyside-edge situation and with a marked south-to-north declivity in parallel with that edge, were also interleaved with the laminated bed; they were a source of both faunal remains and artefacts (Fig. 15). The Greenlands Shell Bed (Bed 5) formed a complex wedge (or double wedge) within the upper part of the interglacial sequence. Thick overlying gravels could not be meaningfully subdivided, there being no higher-level fine-grained unit, and so are classified as Bluelands/Botany Gravel (Bed 6/8), as in the HS1 sections. It is highly likely, however, that its lowest part equates with the Bluelands Gravel as recognized to the east-north-east. It produced a number of artefacts (15), none of them diagnostic.

The intercalation of Bed 4 with Beds 3 and 5 reinforces a view that the various components of this interglacial sequence were probably deposited during a fairly brief period around the MIS 9 (9c?) climatic optimum and that the facies are to a certain extent diachronous. This section is of further importance in that OSL dating samples were collected from it, as will be documented below.

Esso Sports Field (Fig. 1)

The Purfleet Chalk Pits SSSI includes a reserve of undug ground to the west of Greenlands Pit that is of heightened importance now that the west face of that quarry is no longer accessible (see above). In 2006 a proposal to build on this land led to an evaluation of the deposits underlying it, undertaken by drilling 12 boreholes. This revealed that the stratigraphy once visible in the west face of Greenlands Quarry (Fig. 15) can be traced under the northern part of the sports ground, abutting to the south-west against the chalk valleyside (mantled in part with allochthonous chalk), extending towards the ARC 361 00 trenches, and 3953TT and 3954TT, where Beds 3 and/or 4 were also recorded (Fig. 1). Several borehole samples from the northern part of the sports ground were processed for palaeontological analyses (for full details see ArchaeoScape, 2006). Of the 12 boreholes only 4C recorded the full sequence described from the west face of Greenlands Quarry, although 1C also yielded samples of fossiliferous sediments. All the meaningful analyses derive from these two boreholes, the records from which were as follows:

Borehole 1C

Depth (m O.D.)	Thickness (m)	Bed no.	Description
14.5–14.0	0.5	9	Overburden
14.0–8.4	5.6	6/8	Sandy gravel, mainly medium-fine
8.4–7.2	1.2	4	Silt, laminated
7.2–6.6	0.6	2/3	Gravel
unbottomed		0/1	Chalk and ‘coombe rock’

Borehole 4C

Depth (m O.D.)	Thickness (m)	Bed no.	Description
14.5–13.8	0.7	9	Overburden, possibly made ground
13.8–12.4	1.4	6/8	Clayey gravel
12.4–9.3	3.1	6/8	Sandy gravel
9.3–7.9	2.4	5	Sand with shelly horizons
7.9–6.55	1.35	4	Mostly silt, laminated, with interbedded sand
6.55–6.35	0.2	1	Clayey fine gravel; soliflucted?
unbottomed		0/1	Chalk and ‘coombe rock’

Ship Lane, Aveley (Fig. 16; for location see Fig. 1B)

Construction of the new A13 London to Southend road through the Corbets Tey Formation here (see above) during 1997–1998 temporarily exposed lateral equivalents of the Purfleet sediments. Exposed in bridge abutments where the new road passes under Ship Lane were shelly gravels, sands and laminated silts (Fig. 16), resembling similar sedimentary facies within the Corbets Tey Formation at Purfleet, ~1 km to the south. Whereas at Purfleet the deposits are banked against bedrock Chalk to the south, the Ship Lane site would seem to represent the opposite (right-bank) side of the MIS 9 Thames floodplain, with bedrock rising to the north. In addition to duplicating some of the faunas and lithostratigraphy recorded previously at Purfleet, the Ship Lane exposures revealed sediments of different facies that yielded a previously unrecorded terrestrial molluscan assemblage.

The locality is close to the eroded feather-edge of the Palaeogene Thanet Sand, which is preserved above the Chalk north of here and was noted as a thin remnant (above the Bullhead Bed) in the northernmost Ship Lane section(s). The basal Pleistocene deposit, a gravel or sand, contains calcareous concretions (oncoids) similar those characterizing Bed 3 at Purfleet, a potentially important point of comparison (Fig. 16). As the Chalk bedrock surface rises westwards along the new road alignment, the basal deposit is overlapped by younger sediments, comprising variable laminated sands, silts and clays, broadly similar to Bed 4 at Purfleet, and seen in all the exposures. In the south-west (especially section 10725) a sequence of shelly gravel, sand and mud is interbedded between lower and upper laminated units. At the north-eastern end of the site the laminated sequence continues to >5 m and is capped by an upper gravel in the extreme north-east (Bridge section 2). The mollusc faunas from the intermediate beds are not of estuarine character (see below), which means that, if the sedimentological interpretation of the laminated beds as estuarine is correct, there might be evidence for fluctuation of sea-level akin to that invoked to accommodate Bed(s) 7 and/or 8ii at Purfleet. This point should not be overplayed, however, since the proportion of brackish molluscan species at Purfleet is always very small, even when associated with other indications of estuarine conditions. The overlapping upper beds at Ship Lane extend a further ~1 km to the north (Fig. 2), suggesting that the Corbets Tey floodplain was significantly widened during the later part of interglacial.

3.4 Clast analysis (Table 2)

Clast-lithological analysis of the various gravels at Purfleet has been important in contradicting the former view that the sediments were deposited by the Mar Dyke tributary rather than the Thames, an important issue in the debate over whether they record the Last (Ipswichian) Interglacial (cf. Gibbard, 1994, 1995a) or an earlier Middle Pleistocene temperate phase, as is implied if they are part of the Lower Thames terrace sequence (Bridgland, 1994; Schreve et al., 2002; Fig. 3). Further such analyses, arising from the HS1, Armor Road, Greenlands west face and Ship Lane investigations, have now been added to the data set (Table 2). All reveal the typical mix of dominant flint (as nodular material, directly from the Cretaceous, as Palaeogene pebbles or as weathered/broken flint of uncertain derivation), supplemented by Greensand chert from Kent and Surrey and far-travelled (exotic) material from beyond the London basin (cf. Bridgland, 1988, 1994; Schreve et al., 2002). The far-travelled component includes quartz, quartzites, Carboniferous chert, *Rhaxella* chert and very occasional igneous rocks (Table 2). None of the samples indicate the enrichment of Palaeogene flint pebbles or significant dilution of 'exotic' material envisaged for Mar Dyke deposits (cf. Schreve et al., 2002) and all can be safely attributed on this basis to the Thames.

There is little indication of systematic variation in composition between the different gravels, although the pattern of occurrence of non-durable chalk is perhaps worthy of comment. This is largely restricted to basal gravels, just above the eroded chalk surface, or to samples from Bed 6. Excepting basal situations, in which it signifies rapid deposition and minimal transport, such material is more common in interglacial gravels, probably representing single-thread channels (in comparison with the ubiquitous cold-climate braided-river gravels), perhaps because these tend to be more locally sourced and reflect lower energy flow, so that softer material has not been destroyed (e.g., note the occurrence in the interglacial gravels at Swanscombe: Table 2). The occurrence of chalk in Bed 6 might therefore provide tentative support for its potential attribution to the interglacial (see discussion elsewhere) and, in addition, the occurrence of significant chalk in samples of undifferentiated Bed 6/8 might suggest affinity with Bed 6 (this is seen in a single sample, Esso Pit 1B). The observed decalcification of upper parts of the sequence in Greenlands Quarry, including part of Bed 6 (Schreve et al., 2002), limits the potential of this line of evidence.

3.5 Particle-size analysis

Analyses of fine-grained sediments (particularly Beds 4, 7 and 8ii) were undertaken using a Coulter Particle-size Analyser, to determine relative sand, silt and clay component sizes (See Appendix II, online supplement). The finer-grained laminae in Bed 4 were found to consist mainly of silt, with relatively minor (<20%) clay. Similarly, finer grained laminae in Bed 8ii also consist mainly of silt, whereas samples from Bed 7 (from the Greenlands Pit conservation section), although generally dominated by silt, are less well sorted, typically with 25–40% sand (see Appendix II, online supplement). Differences between the various Bed 7 samples support the view that remnant lamination persists in this bed (see above), although the sediment is homogenized in comparison with the much better sorted laminae in Bed 4 or even Bed 8ii. All in all the results conform with the tentative suggestion that all three deposits result from estuarine sedimentation.

3.6 Overview of sedimentology and Palaeogeography

The sequence at Purfleet, slightly expanded here from previous descriptions (see above), records deposition by the Thames under varying conditions of climate and palaeoenvironment. The earliest deposit (following incision to the Corbets Tey terrace level), the slope-derived ‘coombe-rock’ (Bed 1), has been attributed to a cold climate (Schreve et al., 2002), although similar material can be seen to interdigitate with the unquestionably interglacial beds higher in the sequence (e.g. in the Greenlands west face (Fig. 15). Similarly the thin basal fluvial gravel (Bed 2) has been regarded as pre-interglacial, largely from the absence of the fossils that distinguish it from the overlying shelly gravel (Bed 3). There is little sedimentological support for these interpretations, although the faunal evidence from Bed 3 is clearcut. There is a more important role for sedimentology in the interpretation of the more complex interglacial beds, particularly the laminated silt (Bed 4) and its potential equivalents further afield at Ship Lane. As noted by Schreve et al. (2002), this bed comprises laminae typically 1–2 mm thick, separated by partings of fine sand, coarse silt and occasional shell material. They also noted its resemblance of sediments forming tidal mudflats (cf. Allen and Rae, 1987). Bed 4 has now been recognized over a much wider area: in the Greenlands Quarry west face, beneath the adjacent Esso sports field, further west in the sections at Starland and the Esso garage (Fig. 6) and, to the south of the Purfleet Bypass, along the HS1 alignment (within the area of the former Botany Pit). The southern edge of the floodplain during the deposition of beds 3 and 4 is thus now well constrained across the research area (Fig. 1). Within this wider area the bed is somewhat more variable but retains the essential features described above. Whether any part of the Ship Lane sequence is a further continuation of this bed is equivocal. Certainly there are laminated sediments here that fit the same criteria for an estuarine mudflat but they occur at multiple stratigraphical levels (Fig. 16). Assuming these are broadly equivalent to Bed 4, the greater complexity at Ship Lane could result from significant sea-level variation or from minor lateral depositional changes near the margin of the estuary. The records from the Greenlands west face (see above) have also shown that the stratigraphical relations of beds 3, 4 and 5 are more complex than previously recorded, with clear evidence for lateral facies changes between these sediment types at the valleyside margin of the terrace.

The Greenlands Shell Bed (Bed 5), the highest of the unequivocally interglacial sediments at Purfleet, has not been found in the HS1 project area. However, it was well represented in the Armor Road section (Fig. 14) and its known extent has been widened to include the Greenlands west face (Fig. 15) and Esso sports field, from which new studies are reported here, as well as a valuable ostracod-based climatic analysis from new samples from the conservation section (see below). There is little to add to the previous description of its sedimentology (Schreve et al., 2002).

Interpretation of the remainder of the sequence lacks the assistance of fossils. Schreve et al. (2002) were uncertain of the interglacial status of the Bluelands Gravel (Bed 6) and the overlying weathered clayey silt (Bed 7), although they noted ghosted laminae in the latter that were suggestive of intertidal deposition. Amongst the new work reported here, the Armor Road section has most potential to shed further light on this question. The Bluelands Gravel in this section yielded some vertebrate material, although only a tooth of horse was identifiable (Table 3). This animal occurs in both temperate and cold episodes of the Pleistocene and indicates open ground in the vicinity of the site but goes no further in resolving the climatic issues.

The interpretation of this part of the sequence is further complicated by the uncertainty over whether Bed 8ii and Bed 7 are lateral equivalents or whether they represent separate and isolated lenses of fine-grained sediment within a primarily coarse clastic succession. There are indications from both of sedimentation in an estuarine situation; this is stronger for Bed 8ii, based on the recognition of poorly preserved trace fossils (see above) and, in a single sample, a pollen assemblage (see below). If both are remnants of a single second phase of estuarine deposition, the height difference between them, ~5 m (compare Fig. 4 with figure 6 of Schreve et al., 2002), would imply that a substantial body of such sediment once existed and was much reduced by erosion prior to deposition of the post-interglacial (Botany) gravel.

3.7 Palaeogeography: reconstruction of the Corbets Tey Gravel Thames

The z-shaped course of the Corbets Tey Thames between Upminster and Grays is now well established, being supported by palaeocurrent evidence and the distribution of the various Lower Thames terrace deposits in this part of the valley (Bridgland, 1994; Schreve et al., 2002; Fig. 2). Within this looping abandoned course, which narrows to <2 km wide as it cuts through the Chalk of the Purfleet anticline (Fig. 2), the ‘channel’ in which the basal interglacial facies are preserved is narrower still. At Purfleet the interglacial deposits are restricted to the northern parts of the site, being overlapped southwards, onto the Chalk, by the Botany (or Bluelands/Botany) Gravel; this is particularly well illustrated by the section in Greenlands Quarry west face (Fig. 15). Interglacial beds 3 and 4 have been recorded south of the Purfleet Bypass for the first time, in HS1 3953TT and 3954TT, where they are significantly further from the southern margin of the Corbets Tey outcrop than in Greenlands quarry (Fig. 1). In addition, 3957TT exposed the higher-level Bed 8ii, which is also potentially of interglacial origin. At Ship Lane, Aveley, the A13 road construction works exposed what can be interpreted as the north bank of this south-west-trending loop (representing the right bank of the interglacial river), albeit close to the middle of the mapped outcrop, which is a reflection of the continuation northwards of the overlying post-interglacial gravel, which was emplaced on a significantly wider floodplain. For a time during the interglacial (and probably more than once) estuarine conditions reached upstream into the z-shaped loop.

4. PALAEONTOLOGICAL DATA FROM THE NEW SECTIONS

Early palaeontological studies at Purfleet (Hollin, 1971, 1977) emphasized palynological evidence, although this led to an interpretation of the sequence as representing the Ipswichian Stage, which is now regarded as erroneous (cf. Schreve et al., 2002). Indeed, Allen (1977) had raised doubts about this interpretation, based on the molluscan fauna from the Shell Bed (Bed 5), a view reinforced subsequently by Preece (1995). Mammalian evidence has proved the most effective, however, in elucidating the sequence of late Middle Pleistocene interglacials in the Lower Thames, within which the Purfleet beds represent the second of four interglacials, correlated with MIS 9 (Bridgland, 1994; Schreve, 2001; Bridgland and Schreve, 2004). Important supplementary evidence has also been obtained from ostracods and foraminifera.

4.1 Vertebrates

Vertebrate evidence from the various new sections complements and extends the information published by Schreve et al. (2002). New taxa recorded include European pond terrapin and rare avian material. The new samples were as follows:

Eleven bulk samples from the HS1 sections, plus a small amount of vertebrate material recovered during processing of six ostracod samples, as well as isolated finds, mainly of larger material, from the watching brief (Fig. 4; Table 3);

Thirty-four bulk samples throughout the depth of the Armor Road section (Fig. 14), although all finds were from the lower, non-decalcified part of the sequence.

Four bone fragments were recovered from Bed 2 in the Greenlands west face, immediately above the Chalk (locations indicated in Fig. 15) as well as material from bulk and spot samples designed to complement the extensive sampling previously undertaken in the north-east corner of this quarry (Schreve et al., 2002).

Samples from the Esso Sports Field, from borehole 1C (7.95–8.4 m O.D.; Bed 4) yielded well-preserved fish remains (Table 3), including fragile elements such as a cyprinid pharyngeal tooth still in situ in the pharyngeal bone. The predominance of fish remains (to the exclusion of all other vertebrate material) was attributed to a deeper water location than sample points nearer the edge of the deposits, as exposed in the Greenland and Bluelands quarry sections. In terms of composition and preservation, the assemblage from borehole 1C resembles vertebrate remains from the Greenlands Shell Bed (Schreve et al., 2002).

Vertebrate material was also obtained from Ship Lane, from the residues processed for molluscan remains (see below). Methodology for processing vertebrate samples is summarized in Appendix III; full details of the vertebrate analyses appear in Appendix IV.

Combined results

Samples from the lowest fossiliferous stratum (the Shelly Gravel of Bed 3) in the HS1 sections yielded a vertebrate assemblage of clear temperate-climate affinity, as indicated by abundant cyprinid fish (carp family), in particular in samples 264 and 272 from Section 108 (Fig. 6) and Sample 5399 from 5953TT (Fig. 12; Table 3). These suggest the presence of still or slow-flowing water with low levels of dissolved oxygen and high summer water temperatures of at least 18° C (Wheeler, 1969). Local vegetation conditions are indicated by the occurrence in these deposits of bank vole (*Clethrionomys glareolus*), a predominantly temperate woodland species that prefers dense, shrubby undergrowth (Corbet and Harris, 1991). Prevalence of temperate woodland is supported by the record of fallow deer (*Dama dama*) from Bed 3 (Shelly Gravel: Context Oi, Fig. 14) in the Armor Road section and in the Greenlands west face (a well-preserved incomplete left tibia). This species occurred exclusively during temperate episodes during the Pleistocene (Stuart, 1982) and is characteristic of broad-leaf deciduous forest. Additional remains of voles (*Microtus* sp(p) reflect the availability of riparian grassland. Previous examination of the Shelly Gravel revealed evidence for an apparently rapid climatic amelioration within the upper part of the deposit, on account of the presence of cyprinid fish and thermophilous Mollusca (Schreve et al., 1998).

Identifiable remains of large mammals, rarely encountered in any of the deposits, usually consisted of teeth, which are more commonly preserved in fluvial deposits than bones on account of their relative durability. The dental remains of fallow deer (*D. dama*) and red deer (*Cervus elaphus*) recovered from Bed 3/Oi at Armor Road are in an excellent state of preservation, probably as a result of the high carbonate content of this deposit and only negligible downstream transportation. A single premolar of *C*. *elaphus* was recovered from Bed 3/Oii at Armor Road. Identifiable bones of large vertebrates from Bed 3 were equally rare in the HS1 exposures. Part of the right humeral diaphysis of a large bovid and the distal right humeral diaphysis of red deer were found in the watching brief (Fig. 4). The specimens are well mineralised but display evidence of rolling, abrasion and longitudinal cracks on the bone surface. Only where extensive carbonate deposition has resulted in the formation of a solid crust (calcareous oncoids: see below) around the outer surface is bone preservation substantially improved: for example a well-preserved partial right ilium of deer (cf. red deer). The remainder of the large bone fragments are in much poorer condition and are, unfortunately, indeterminate. One notable feature noted amongst material from Section 108 (Fig. 6) is that some of the vole molars bear the traces of digestion by an avian predator, suggesting that they were originally incorporated into the fluvial deposits within bird pellets.

The HS1 sections revealed fossiliferous facies not observed in the various quarry sections. In particular, a loose, brown current-bedded sand with shell fragments (Section 108, Context 119, Sample 264; Fig. 6) proved especially rich in vertebrate remains. The assemblage from this bed is again dominated by cyprinid fish, in particular roach (*Rutilus rutilus*) and rudd (*Scardinius erythropthalmus*). The recovery of pharyngeal teeth still in situ in the pharyngeal bone indicates a gentle depositional environment at the time and subsequent lack of disturbance. A small number of undetermined frog or toad bones were also recovered from this bed, together with remains of probable field vole (*Microtus* cf. *agrestis*), a species characteristic of rough, damp grassland (Corbet and Harris, 1991). A compact yellow silty clay slightly lower in the stratigraphy (Section 108, Context 120, Sample 296; Fig. 6) proved to be less fossiliferous, yielding only a small number of cyprinid pharyngeal teeth. Both these samples are tentatively placed in the uppermost part of Bed 3, although the sandy facies overlies a silty horizon that is not typical of that bed and may be transitional between beds 3 and 4. Indeed, these two beds were clearly seen to be interstratified in the Greenlands west face (see above; Fig. 15).

As noted in previous Purfleet sections, the typical laminated facies of Bed 4 were very poor in vertebrate remains, although samples from sandy intercalations within this unit (Starland section, samples 514 and 515 and Esso garage section, Sample 499; Fig. 6) were rich in fossils, with a diversity of small vertebrates (Table 3). As before, the assemblages were dominated by cyprinid fish, with their associated predator, the pike, together with freshwater eel and three-spined stickleback (*Gasterosteus aculeatus*). The last is extremely widespread today in all waters and in coastal and estuarine conditions. In freshwater settings, such as at Purfleet, it is least common in stagnant, densely-weeded areas (Wheeler, 1969). The high summer-water-temperature requirement of the cyprinids has already been noted; the presence of these species indicates interglacial conditions and a large, slow-flowing body of water at the time of deposition. Herpetofaunal remains are represented by frog or toad, together with a single vertebra of undetermined snake. A diversity of small mammal remains, including wood mouse (*Apodemus sylvaticus*), field vole or common vole (*Microtus agrestis* or *M*. *arvalis*) and water vole (*Arvicola terrestris cantiana*) are indicative of a combination of woodland, grassland, riparian and aquatic environments. A sample from a sand lens within the laminated silty clays in the Greenlands Quarry west face yielded a similar range of taxa, with the notable addition of a carapace fragment of European pond terrapin (*Emys orbicularis*), the first record of this reptile from Purfleet (see Appendix IV, online supplement). This species, today exotic to the British Isles, is of particular palaeoclimatic significance, since it requires mean summer temperatures of 18ºC (approximately two degrees warmer than southern Britain at the present day) in order to incubate its eggs (Stuart, 1979). A single, very small upper canine is attributed to a member of the weasel family (*Mustela* sp.), also a new record for the site. Vertebrate fossils also occurred in the Greenlands west face within chalky lobes, presumably in part derived from the valley-side slope, interbedded with the laminated silts of Bed 4 (Fig. 15, sample F7 see also Appendix IV, online supplement).

The Greenlands Shell Bed (Bed 5) has consistently proved to be the richest source of fossil vertebrates at Purfleet, although it is only present in the northern part of the site, in Greenlands and Bluelands quarries and beneath the Esso Sports Field, and was not recorded in the HS1 sections. Samples of the Shell Bed were, however, collected from the west face of Greenlands Quarry and from Contexts K–M at Armor Road. The quality of preservation of the material from these samples is excellent, with fragile small-mammal postcranial bones (such as a complete microtine rodent humerus) and delicate bird bones present. In accordance with the results of previous investigations (Palmer, 1975; Snelling, 1975; Allen, 1977; Hollin, 1977; Holman and Clayden, 1988; Schreve, 1997; Schreve et al., 2002), fish were most abundantly represented, with smaller numbers of Soricidae sp. (indeterminate shrew), wood mouse, indeterminate vole, water vole, frog or toad (*Rana* or *Bufo* sp.), newt (*Triturus* sp.) and undetermined snake. Three avian bones were identified by Dr Joanne Cooper as Passeriformes sp. (perching birds), goose (*Branta* or *Anser* sp.) and an indeterminate bird. Of these the goose is the most valuable palaeoenvironmental indicator, since both genera are migratory, with distinct breeding and wintering areas. Typically the breeding grounds are in open grassland habitats, which can include tundra, heathland and steppe, usually with open water nearby. Wintering ranges also tend to be associated with open waters, such as estuaries or coastal mudflats, with grasslands also used for grazing (J. Cooper, pers. comm.).

These new data conform fully with the palaeoenvironmental reconstruction by Schreve et al. (2002) on the basis of investigations in the north-east corner of Greenlands Quarry (their section 2: Fig. 14), which demonstrated deposition of the Greenlands Shell Bed under fully interglacial conditions. The presence, in particular, of white-toothed shrew (*Crocidura* sp.) was considered significant, since this has a predominantly southern European present-day distribution and its occurrence might thus indicate a climate slightly warmer than at present. The small mammals continue to reflect a range of terrestrial and aquatic habitats, whereas the larger mammals recovered from Greenlands north-east corner, in particular macaque monkey (*Macaca sylvanus*), European beaver (*Castor fiber*), roe deer (*Capreolus capreolus*), fallow deer and straight-tusked elephant (*Palaeoloxodon antiquus*), suggest the proximity of deciduous or mixed woodland. Two exotic frog species were recorded in the Greenlands Shell Bed by Schreve et al. (2002), the agile frog (*Rana* *dalmatina*), which inhabits predominantly dry, often wooded habitats, and the highly aquatic pool frog (*Rana lessonae*). Common frog (*Rana temporaria*), moor frog (*Rana arvalis*) and grass snake (*Natrix natrix*) were also present (Schreve et al., 2002).

Correlation of the limited but very well preserved vertebrate assemblage obtained from the Ship Lane site is difficult, since it apparently represents a terrestrial-dominated depositional facies with no immediately apparent correlative at Purfleet. Certainly the combined presence of bank vole and wood mouse (Table 3) reflects fully-temperate conditions and broad comparison with the Greenlands Shell Bed would not be inappropriate.

The preservation quality of the few vertebrate remains from strata above the Greenlands Shell Bed varies considerably, even between specimens from a single horizon. This is particularly obvious in material from Bed 6/I (Bluelands Gravel) at Armor Road, where some specimens show evidence of polishing (possibly by aeolian action) and others of post-depositional breakage. Multiple histories of deposition and probable reworking therefore seem likely. None of this material was identifiable. Horse (*Equus ferus*) was represented by a single lower premolar from Bed 6/J, which is the basal lag of the Bluelands Gravel, a situation in which reworking from the underlying shell bed is a distinct possibilty. In addition, Sample 500, from the HS1 Esso Garage Section (from a loose yellow-brown sand transitional between Bed 4 and generic ‘upper gravel’: Fig. 6) yielded a single indeterminate fish vertebra. These finds represent meagre evidence upon which to judge, but the hint that the Bluelands Gravel is part of the interglacial sequence is unsurprising and would support the view that the enigmatic Bed 7 is likewise a weathered temperate-climate (estuarine) deposit, as has been suggested previously (Schreve et al., 2002; see above).

Added to the above, A.J. Snelling (in Roe, 1981) recovered a sparse mammalian fauna from the gravel in Botany Pit during his excavations there, which produced the (proto)Levallois material first reported by Wymer (1968). In the absence of Bed 7 at this site, this gravel would have to be classified as Bed 6/8. The finds consisted of horse, red deer, indeterminate elephant and aurochs (*Bos primigenius*), the last in particular hinting at a warm climate. Again the suggestion is that the full Purfleet sequence, including the upper gravels, pre-dates the end of MIS 9, although it was noted above that the Botany Pit sequence might well have included the Bluelands Gravel.

4.2 Molluscs

The molluscan fauna from the Greenlands and Bluelands quarry exposures at Purfleet has been extensively researched since the sites were first described (Allen, 1977; Preece, 1995; Keen, in Schreve et al., 2002). Only modest appraisal was therefore undertaken of the molluscan evidence from the HS1 sections and the new sections in Greenlands Quarry. Most of the samples from the HS1 sections were relatively poor in Mollusca, the prolific Greenlands Shell Bed being absent from the alignment of the railway. The most fossil-rich parts of the shelly gravel (Bed 3) were generally difficult to study because of calcareous encrustation of the material. The new observations have added little to Keen’s list from this bed in Bluelands Quarry (in Schreve et al., 2002): *Unio pictorum* was identified, amongst fragmentary Unionid material that clearly included other taxa. In addition, two further specimens of the large freshwater mussel *Margaritifera auricularia* were recorded in situ in this bed in the Greenlands Quarry west face sections (Figs 15 and

17), confirming the occurrence of this now-rare bivalve in the MIS 9 Thames (cf. Preece, 1988).

Keen (in Schreve et al., 2002) made exhaustive studies of the Greenlands Shell Bed (Bed 5), based on six serial samples from Greenlands Quarry Section 2 (see Fig. 14, inset; Table 4; see also Appendices I and III, online supplement). One randomly selected sample (Sample 4) was counted in its entirety, yielding 10,400 shells (plus 8982 *Bithynia tentaculata* opercula). The standard of preservation was good, with only the land snails somewhat damaged by transport, in keeping with interpretation of the shell bed as a fluvial accumulation of mostly riverine shells into a sand bank, with rarer terrestrial shells incorporated from further afield, having been washed into the river (Schreve et al., 2002). A sample from Context L (Bed 5) in the Armor Road section can now be added to the Greenlands Quarry data (Table 4). The assemblage from here closely resembles those from the shell bed in Section 2, 25 m to the east.

The exposures in the A13 road works near the Ship Lane bridge have provided valuable new molluscan data, complementing those from Purfleet and revealing previously unrepresented facies. Eight samples were examined from here, some from within recorded sequences and others from individual shelly pockets of sediment identified in the cutting sides and spot sampled (Fig. 16; for preparation details, see Appendix III, online supplement). Preservation quality was variable: material from sand and gravel contexts was often badly leached, such that much shell was corroded and in the worse cases only the largest survived, although in chalky mud facies preservation was excellent, with even the smallest gastropod species preserved.

There were difficulties in identifying some of the specimens, especially (amongst the land Mollusca) the Clausiliidae (from Bed 5 at Armor Road and from Ship Lane: Table 4), which, except for a single *Clausilia pumila*, were preserved only as broken shells that seldom included the diagnostic aperture. Many of the fragments were ribbed, with a close pattern of 11 ribs per mm, identical to that of modern *Clausilia bidentata* (cf. previous records from Beds 3 and 5 in Greenlands and Bluelands quarries (Schreve et al., 2002)) and so attributed to that species. Other fragments had a much wider spaced rib pattern of around 5-6 per mm, clearly different from *C. bidentata*, but they could not be positively identified to species. One shell with five of the upper whorls preserved and a wide-spaced rib pattern was of too great a diameter to be any likely species of *Clausilia* and is tentatively identified as *Macrogastra ventricosa* on the basis of ornament and size. As with the Clausiliidae, most of the remains of *Discus* were of fragments rather than whole shells; comparison of these remains with intact shells of *Discus rotundatus* and *Discus ruderatus* from elsewhere showed that fragments exhibiting the different rib patterns of both of these species were present.

The Ship Lane assemblages are notably richer in Planorbidae and Lymnaeidae than those from Purfleet, suggestive, respectively, of more plant cover and lower water depths, in comparison with the better-known site. The well-preserved Ship Lane fauna indicates habitats of calcareous fen (*Vertigo* spp.) and chalk grassland (*Truncatellina cylindrica*, *Pupilla muscorum, Vallonia* spp.), not represented at Purfleet and thus complementary to the scrub and shaded habitats indicated by elements of the Greenlands and Bluelands sequences. The ultimate site of deposition of these Ship Lane deposits was in shallow quiet water, however, as indicated by the minority aquatic element in these samples.

4.3 Ostracods

Twenty-six samples from the HS1 sections were submitted for microfossil analysis (for methodology, see Appendix III, online supplement). Fifteen samples from Section 108 (samples 103–114 and three further samples from monoliths 101 and 102; Fig. 6) were particularly informative, most containing ostracods (Table 5), although no foraminifera were found in any of them. Ostracods were also obtained from 3953TT (Sample 5399, shelly gravel; Fig. 12). Samples from the Esso Garage site (Fig. 6) were either barren or yielded only a few ostracods (Table 5).

In addition, a new investigation was undertaken of ostracods from the Greenlands Quarry north-east section (Fig. 14; Section 2 of Schreve et al. 2002), involving analysis of four samples: one from the lowest from the shelly bands within the Bed 4 silty clay, and the other three from Bed 5 (Greenlands Shell Bed). The Bed 4 shell band contains essentially the same mollusc assemblage as Bed 5 (Schreve et al., 2002) and, by comparison with the section at the western end of Greenlands Quarry (Fig. 15), may well be an intercalation of the lower part of Bed 5 into Bed 4. Abundant ostracods were obtained (Table 5), permitting taxonomic revisions and the derivation of palaeotemperature estimates (see below).

In Section 108, *Cyprideis torosa* occurred from sample 112 up to 103 (Table 5), all of them noded, demonstrating a tidal influence towards the top of Bed 3 and into Bed 4 (Fig. 6), always assuming they were not reworked from estuarine sediments upstream. Noded *C. torosa* signify a salinity of <6‰ (Meisch, 2000), whereas smooth populations (not seen at Purfleet) are found in higher salinities. Charophyte oogonia, remains of a plant indicative of shallow clean water fringing the main river, also occured in Bed 3, accompanied by *Bithynia* opercula (probably washed in) and some fish teeth (Table 5). The nature of the Bed 3 sediments and their (sparse) organic content suggest a very high energy, mainly fluvial environment. Higher in the bed, finer sandy deposits, but still of quite high energy, yielded heavily noded *C. torosa* throughout (Fig. 18 a, b), with a few non-marine ostracods in sample 110. In addition to fossils considered under other headings, there were also calcareous tubes (formed around rootlets and stems, and usually found where tidal flats occur and subaerial erosion takes place). There is therefore clearly a mixture of (low) brackish and freshwater influences, as would be expected in the high-energy estuarine environment at the mouth of a large river.

The residues of the finer sediments that make up Bed 4 (samples 103–108) yielded a very large number of calcareous rootlet and stem tubes (Table 5), common brackish and non-marine ostracods, and *Bithynia* opercula (but no mollusc shells). Significantly, the samples lacked charophyte oogonia, fish or small mammal remains. Noded valves of *C. torosa* are typical of all brackish Thames/Medway interglacial sites, especially those of MIS 9 age; indeed, the coeval Grays (Essex) ‘brickearth’ provides the type-locality of this species (Jones, 1850). Co-occuring at Purfleet are several ostracods typical of the fringes of tidal rivers in very low brackish conditions, including *Ilyocypris decipiens*, *Darwinula stevensoni* and *Limnocythere inopinata*. These findings therefore concur with previous interpretations of Bed 4 as deposited in a low-energy estuarine environment.

To supplement the above data, additional ostracods were extracted from the two monoliths (102 and 101) from Section 108 (Fig. 6; Table 5). Monolith 102, covering the Bed 3–4 transition, contained common *C. torosa*, represented by adults and juveniles from A-3 to A-5; adults were all noded but the smaller juveniles were smooth. The absence of A-1 and A-2 instars is puzzling and may indicate that the assemblage has been subjected to post-mortem transport and sorting. The occurrence of adults and juveniles (down to A-4) of *Darwinula stevensoni* suggests that this species, at least, was in situ and thus indicative of freshwater conditions. The assemblage from the lower part of monolith 101 (equivalent to

106–108 of the above-described samples; Bed 4) included relatively abundant *Darwinula stevensoni* (adults and juveniles), common *Ilyocypris* sp. (adults and juveniles) *C*. *torosa* (juveniles only, mainly smooth forms) and rare *Limnocythere inopinata* (adult males and females and juveniles), *Candona* sp. (juveniles) and *Cyclocypris* sp., possibly indicative of freshwater conditions at the limit of tidal penetration. The upper part of monolith 101 (equivalent to samples 103–105; Bed 4) contained common in situ *C*. *torosa* (all noded, adults and juveniles) and rare *I*. *decipiens* (adults) and *Candona* sp. (juveniles); there is therefore a hint of increasing salinity and/or tidal influence from bottom to top of this section.

A shelly sample (5399) from Bed 3 in 3953TT (Fig. 12; Table 5) also merited further attention, being rich in ostracods as well as containing molluscs (including *Bithynia* opercula), charophyte oogonia, and the vertebrate remains described above. The deposit and its microfossils are very reminiscent of the shelly facies at Greenlands Pit (Whittaker, in Bates et al., 2002). In particular both contain *Ilyocypris salebrosa*, a marker species for MIS 9 (see below) that co-occurs at the present locality with *Scottia tumida*, another species of biostratigraphical significance (see below). The *C*. *torosa* specimens are well noded and all the non-marine ostracods present are species that can tolerate low salinities in tidal rivers, as seen in previous samples.

The assemblages from all four samples from the north-east section of Greenlands Quarry (Table 5) were essentially similar and are considered here as a single assemblage; in all, 13 ostracod taxa were recorded. Representative specimens of key taxa are illustrated in Figs 18 and 19. *C*. *torosa* was dominant (approx. 45% of the total assemblage) and occurred in both its noded and smooth forms. The genus *Ilyocypris* was also abundant, constituting ~16% of the assemblage and represented mainly by *I*. *decipiens* and *I*. *lacustris*, with rarer specimens of *I*. *inermis* and *I*. *salebrosa*. Other components (each ~10% or less) were *Darwinula stevensoni*, *Limnocythere inopinata*, *Cytherissa lacustris*, *Candona neglecta*, *Fabaeformiscandona caudata*, *Scottia tumida* and unidentified species of *Herpetocypris* and *Pseudocandona*. The fauna is broadly similar, in terms of its dominant components, to that described by H.I. Griffiths (in Schreve et al., 2002) from the same deposits, but with some significant differences. The species termed by Griffiths '*Ilyocypris* sp. A' is now known to be *I*. *salebrosa* (see Bates et al., 2002). Several taxa recorded by Griffiths were not identified in the present study: *Candona candida, Fabaeformiscandona balatonica*, *Ilyocypris gibba*, *Metacypris cordata*, *Pseudocandona rostrata* and *Scottia browniana*. Although some of these differences may be attributed to the higher-resolution sampling of Bed 5 by Griffiths (six samples as opposed to three in the present study), in at least one case the explanation probably lies in different taxonomic interpretation of the same ostracod: the relatively abundant *I*. *gibba* recorded by Griffiths is almost certainly the taxon identified here as *I*. *decipiens*. Griffiths' (unillustrated) identification of *S*. *browniana* as well as *S*. *tumida*, which has not been repeated in the present study, is contentious, since this taxon is otherwise unknown in Britain after the Hoxnian (MIS 11) interglacial (Whittaker and Horne, 2009). Taphonomic analysis of the population age structure of *C*. *torosa* was conducted separately for each of the four Greenlands Quarry samples. In every case the presence of adults and juveniles, down to and including A-5, suggests that the fauna was deposited in situ and that the assemblage is, therefore, a reasonably reliable representation of the biocoenosis living in the region during MIS 9, although variations between samples are suggestive of fluctuations in flow conditions; the rarity of articulated adult carapaces and the absence of valves of the smallest juveniles (A-6 and below) may indicate disturbance/winnowing by currents. The presence of juveniles as well as adults of all the other species present in the assemblages supports the conclusion that the ostracod fauna is essentially in situ (an autochthonous thanatocoenosis) and therefore representative of local environmental conditions.

With the exception of the extinct *I. salebrosa* and *S. tumida,* modern representatives of all the species identified can be found living in Europe today. The dominance of noded *C. torosa* and the presence of *D. stevensoni, L. inopinata* and *C. neglecta*, which, although typically freshwater species, can tolerate low salinity, indicate fluvial or inner estuarine conditions of no higher than 6‰ salinity. The assemblage is consistent with a slow-flowing river or backwater/marsh environment, with aquatic vegetation, close to the upstream limit of tidal influence. Minor changes in the assemblage composition, notably an increase of *C. lacustris*, a freshwater species tolerating salinity of up to 1.5‰ (Meisch, 2000), and a decrease in the abundance of *C. torosa*, are suggestive of decreasing salinity towards the top of Bed 5. The presence of both males and females of *L. inopinata*, as recorded by Schreve et al. (2002), is confirmed. Today this species shows geographical parthenogenesis in Europe, sexual populations being known only from the Balkans, Anatolia and the Caucasus (Meisch, 2000), while all-female populations are widespread; fossil sexual populations have been recorded in north-west Europe in the Lateglacial–early Holocene and in previous interglacials (Horne and Martens, 1999).

Climatic indications from the Purfleet ostracod fauna

Mean July and January air temperature ranges were estimated using the Mutual Ostracod Temperature Range (MOTR) method (Horne, 2007), based on the Non-marine Ostracod Distribution in Europe (NODE) database (Horne et al., 1998). The following species recorded from Bed 5 in the present study and by Schreve et al. (2002) were included in the application of the method: *Candona neglecta, Cypridopsis vidua*, *Cytherissa lacustris*, *Darwinula stevensoni*, *Fabaeformiscandona caudata*, *Ilyocypris inermis*, *Ilyocypris decipiens*, *Limnocythere inopinata, Metacypris cordata* and *Pseudocandona rostrata*. Some species were not used, either because they are extinct and so cannot be calibrated (e.g. *S. tumida*) or because of taxonomic uncertainties (as in the case of *I. bradyi* and *I. gibba*). Horne and Mezquita's (2008) revised calibration of the modern temperature ranges of ostracod species was adopted. For *I. decipiens*, a species not previously calibrated, analysis of its 28 records in the NODE database gave ranges of +15 to +25^{o}C (July) and -8 to +6^{o}C (January).

The application of the MOTR method to the Purfleet Shell Bed assemblage yielded the following results:

July mean air temperature range of +16 to +21^{o}C

January mean air temperature range of -3 to +3 ^{o}C.

Comparison with modern mean air temperature values for the Purfleet area, as obtained from the same climate data set as used for the calibration, shows that the modern July value (17.6^{o}C) falls within the MIS 9 MOTR estimate. However, the January MOTR indicates colder winters than the present-day mean January air temperature of 4.5^{o}C. Overall this points to full interglacial conditions but perhaps with greater 'continentality', perhaps raising questions about Britain's island status during MIS 9 (see below). These findings are consistent with Schreve et al.'s (2002) estimates for the Purfleet deposits based on molluscs (fully temperate, greater continentality), fish (summer water temperatures of at least 18^{o}C) and a single record of a green frog (mean July temperature of at least +15 to +17^{o}C). As noted above, the newly recorded occurrence of *E. orbicularis* might imply that summers were somewhat warmer than at present.

For comparison with the estimates from Purfleet, MOTR analyses have been conducted on published ostracod assemblages from other MIS 9 sites in the Thames–Medway area:

Hackney (Green et al., 2006), Barling (Bridgland et al., 2001) and Allhallows (Bates et al., 2002). The results are similar, as can be seen from Table 6, and are consistent with previously published temperature estimates obtained using the coleopteran Mutual Climate Range method: +17 to +26^{o}C (July) and -11 to +13^{o}C (January) for Barling (Bridgland et al., 2001); +18 to +19^{o}C (July) and -4 to +1^{o}C for Hackney (Green et al., 2006). The MOTR estimates for Barling and Hackney differ slightly from those previously given by Horne (2007) due to the use of revised calibrations as noted above.

4.4 Palaeobotany (palynology)

All previous successful palynological studies at Purfleet, based on sporadic spectra from suitable laminae within Bed 4, have suggested deposition under temperate, interglacial conditions in a fluvio-estuarine environment, although there has been controversy over the dating and correlation of the interglacial. Hollin's (1977) analysis showed dominance of *Quercus* and *Pinus* with abundant *Alnus* and *Corylus* and few herbs, interpreted as a wooded, temperate interglacial environment of suggested Ipswichian (Ip IIb) age. A single pollen sample from Greenlands Quarry examined by Holyoak (in Gibbard, 1994) showed less *Alnus* than in Hollin’s analysis but with small frequencies of *Carpinus* and greater numbers of herbs (Poaceae). This was interpreted as being slightly later in the (Ipswichian) interglacial. West (in Gibbard 1994) produced results similar to those of Hollin, this time from Bluelands Quarry but, with the addition of small numbers of *Picea* and *Abies* in association with important *Quercus*, *Pinus*, *Alnus* and *Corylus*. Gibbard’s conclusion was that the age was broadly Ipswichian IIb. Bridgland et al. (1995) highlighted poor preservation and resultant skewed taphonomy, typical of estuarine and fluvial sediments (with, e.g., possible over-representation of saccate pollen grains such as *Pinus*), as a potential reason for the difficulties with interpretation of the Purfleet palynological data.

Blackford (in Schreve et al., 2002) undertook the most comprehensive previous palynological study at Purfleet, forming part of multidisciplinary work at Greenlands Quarry. He analysed 32 relatively closely spaced samples from Bed 4, although in many of these pollen was absent or present in less than statistically valid quantities. Nonetheless, there was sufficient to produce the first pollen diagram from the site, demonstrating a full interglacial flora with *Alnus*, *Picea* and *Quercus* dominant. *Pinus* was also present, but in smaller numbers than noted in earlier work (or, indeed, in that presented here). Herbs were also more abundant than had been previously recorded. These pollen data and associated palaeoecological and sedimentological studies provided a clearer view of the palaeoenvironment of the Purfleet interglacial. In summary, they demonstrated sedimentation in water up to 5 m deep, with some, but minimal, saline influence. The vegetation was of fully temperate character with local mixed woodland and grassland in the vicinity of the river. This was the context for a renewed attempt at palynological stuidy of the Purfleet sediments.

HS1 samples: Bed 4

The two monoliths, 101 and 102, from Beds 3–4 in Section 108 (Fig. 6) were amongst several assessed by B.A. Haggart (in URL, 2001), who found that 101 had the best potential for producing countable pollen. A total of 19 samples from this monolith were thus processed (see online Appendix III for methodology), 15 of which yielded useful pollen counts. Small numbers of grains observed in the remaining samples were too few to be statistically valid and were thus not included in the new pollen diagram (Fig. 20). Although saccate grains were typically broken, the presence of fine-walled pollen in some samples demonstrates that the procedure, which involved hydrofluoric acid (Appendix III), was not too severe. In the case of broken bisaccate *Pinus*, in addition to counting any whole grains, individual sacs (± body) were counted and numbers halved, whereas lone bodies (without sacs) were not included. The problem of *Picea* fragments, as discussed by Schreve et al. (2002), did not arise, given the smaller numbers of this taxon encountered. Pollen sums varied from a minimum of 50 grains (at 6.38 m.O.D.) to 300–600 grains per level, depending on preservation (Fig. 20).

Zonation

Five local pollen assemblage zones have been recognized, based on the inherent changes in the pollen assemblages, although to a large extent delimited by the complex stratigraphy of the sediment sequence. Zones 1–3 fall within the lower stratigraphical unit, comprising laminated clayey silt and fine sand (Bed 4; context 106, Fig. 6). Zone 4 and the lower part of zone 5 fall within overlying silty clay in which pollen was sparser, corresponding with lithologically similar contexts 107 and 108. Pollen was absent in fine sands between 6.50 m and 6.56 m (sand lens in Fig. 6). The upper portion of zone 5, with better preservation, coincides with the laminated clays and silts of context 109. Trees and shrubs are dominant throughout the sequence with only a single sample containing substantial herbs (largely Poaceae). Algal *Pediastrum* cysts are present throughout, along with fluctuating values of dinoflaggellates. The latter were kindly examined by Prof. Rex Harland, who determined them to be entirely of Palaeogene origin and therefore reworked.

Zone 1: 6.06–6.12 m O.D. *Pinus* is dominant (peak to 83%), with *Quercus* (10–21%) and *Alnus* (to 6%). Small numbers of *Picea, Tilia*, *Fraxinus*, *Corylus avellana* type and *Salix* (<1%) are present. Although there are only small numbers of herbs (9%), diversity is greater than in subsequent levels, with Poaceae (10%) the most important. Marsh/aquatic taxa include occasional Cyperaceae, *Typha angustifolia* type and *Menyanthes trifoliata*. Spores comprise monolete forms (*Dryopteris* type).

Zone 2: 6.12–6.19 m. O.D. *Pinus* values decline (to 24%) with expanding *Quercus* (to 35%) and *Alnus* (to 18%). There are small numbers of *Picea*, *Tilia*, *Fraxinus*, cf. *Acer* and *Hedera helix*. Herbs, spores and miscellaneous types (*Pediastrum* and dinoflaggellates) are as in the preceding zone.

Zone 3: 6.19–6.24 m O.D. *Pinus* values are at a minimum of 15% at 6.22 m but subsequently increase. Correspondingly, *Quercus* peaks to its highest values (78%). High values of *Alnus* in the preceding zone (2) are reduced to *c*. 5%. *Tilia* is absent. Herbs consist largely of Poaceae (to 10%). Marsh taxa remain the same as previously. There is a reduction in *Dryopteris* type spores. Dinoflaggellates increase from <5% to 12% (sum + misc.). Derived (pre-Quaternary) palynomorphs are more abundant.

Zone 4: 6.24–6.36 m O.D. This zone is delimited by an expansion of *Pinus* (to 65%), consequent upon reduction of the previously high values of *Quercus* in zone 3. The latter, however, remains important (to 40%). There are also small numbers of *Abies* and *Picea*. *Alnus* declines to absence. Other pollen taxa remain the same as in the previous zone, with herbs comprising largely Poaceae (10%) and small numbers of Lactucoideae (1–2%). Dinoflaggellates reach their highest values at 6.38 m (38% sum + misc.)

Zone 5: 6.36–6.68 m O.D. *Pinus* attains its highest values (99% at 6.42 m O.D.) and is the dominant arboreal taxon throughout this zone. *Quercus* has lower values than previously (av. 10%) with small peaks of *Alnus* (10%) and *Corylus avellana* type (6%). *Erica* and *Calluna* are present at 6.18 m (<2%). Herb numbers remain small but with sporadic *Plantago lanceolata* type present only in this zone and a substantial peak of Poaceae (38% at 6.58 m). Marsh/fen taxa comprise Cyperaceae, *Typha latifolia*, *Typha angustifolia* type, *Azolla filiculoides* and *Pediastrum* (20–25% Sum + Misc.). There is some increase in *Dryopteris* type (peak to 7% at 6.28–6.32 m) and *Pteridium aquilinum* (<1%).

Synthesis

This pollen sequence (Fig. 20) is clearly of interglacial status, with a range of woodland taxa of temperate affinity. These comprise largely *Pinus* with small numbers of other coniferales, including *Abies*, *Picea* and a substantial temperate deciduous flora: *Quercus*, *Corylus avellana* and *Alnus* (especially in zone 2), with ephemeral but under-represented *Tilia*, *Fraxinus* and *Salix*. The dominance of *Pinus* throughout can probably be attributed to the fluvial deposition, with over representation of pine caused by floating of these saccate grains in standing water (cf. Faegri and Iversen, 1989; Schreve et al., 2002; Roe et al., 2009).

A change in the stratigraphy at ~6.24 m O.D., from laminated sandy silts to finer-grained silts, is also associated with changes in the palynology. Zones 1–3 show a sequence in which *Pinus* is initially dominant with *Quercus*. *Abies*, *Picea*, *Tilia* and *Fraxinus* are all present and, as taxa that are poorly represented in pollen spectra, may be assumed to have been of some importance at this time. *Quercus* appears to peak in zone 3, after early importance of *Pinus*. Although there are problems in interpretation caused by the possible over representation of *Pinus*, it is possible that these changes show a successional development from pine- to oak-dominated woodland. However, an ‘early temperate’ interglacial biozone is not thought likely due to the record of fully temperate woodland types from the base of the profile. Subsequently, values of *Quercus* decline while *Pinus* remains important, with minor but consistent presence of *Picea* and *Abies* throughout zones 4 and 5. Whilst genuine vegetational change is envisaged for the better preservation in zones 1–3, the subsequent expansion of *Pediastrum* and dinoflaggellates may indicate a more complex taphonomy, with the often-quoted over representation of pine in what is clearly a fluvial sediment, which has been suggested as representing up to 5 metres water depth (Allen et al., 2000).

Salix and *Alnus* in zones 1 and 2, respectively, are from growth in floodplain carr associations, with fen herb taxa (*Typha*/*Sparganium*, *Sagittaria* and Cyperaceae). The fluvial derivation of the sediments is, however, indicated by *Pediastrum*, *Menyanthes trifoliata* and *Potamogeton* type. *Alnus* is most prevalent in zone 2 (6.14–6.18 m O.D.), after which values are small for this generally over-represented taxon. This is interpreted as being a change to aquatic and deeper-water conditions (as noted above), evidenced by increases of *Pediastrum* and dinoflaggellates. There is, however, no pollen of aquatic macrophytes, with only *Azolla* and some marginal/fen taxa present. Bed 4 has been interpreted as estuarine (see above) but there is no palynological evidence in support of this, with the absence of typical halophytes such as Chenopodiaceae or Plumbaginaceae; however Haggart (in URL, 2001), in his preliminary assessment of this profile, observed two badly degraded Chenopodiaceae grains.

Previous studies have established the Purfleet sequences as interglacial, with a range of temperate woodland taxa (Bridgland et al., 1995; Schreve et al., 2002). The differences between these data sets are of potential interest. Schreve et al. reported a dominance of thermophilous trees (*Alnus*, *Quercus*, *Tilia*, *Fraxinus*, *Ulmus*) in an open mixed forest, with *Picea* of substantial importance, especially given that this taxon is poorly represented in pollen assemblages in general. Although they suggested that spruce values were probably over-represented, it appears that there was a significant episode of spruce domination (or at least significance). This was also seen in the analysis of samples from Stonehouse Lane, immediately east of Greenlands Quarry, although the scanty pollen spectra there were regarded as residual taphonomic artefacts (Tipping, in Bridgland et al., 1995). In contrast, there are only very small numbers (<1%) of spruce in the new spectra from HS1 (Fig. 20). The latter, however, also has small numbers of *Abies*, which has seldom been recorded previously. *Abies* pollen, being a saccate type, may also suffer skewed representation in pollen assemblages, although, as with *Picea*, it is largely under-represented due to its large size. Thus, as with *Picea*, occasional local presence is suggested as part of the pine/conifer community.

In the HS1 analysis (Fig. 20), *Pinus* appears to have higher values than in previous studies. The possibility of this being re-worked Tertiary material was considered but rejected (there are only small numbers of re-worked palynomorphs). Clearly pine might be over represented, for reasons described above, but it appears that pine woodland was of some importance throughout the period represented. *Quercus* is important and common, as in previous profiles examined, along with a range of other trees (e.g. *Ulmus*, *Tilia*, *Fraxinus*) and shrubs that have been used to establish the interglacial affinity of these sediments (Hollin 1971; Scaife 1998; Allen et al., 2000; Schreve et al., 2002). These taxa are considered to represent the local and regional woodland, whereas *Alnus*, similarly characteristic of all profiles, and *Salix* were elements of the river-floodplain (carr) vegetation, along with fen herbs (reed swamp) and aquatics.

It is apparent from the uniformity of faunas from the interglacial beds and the interfingering of these in the west face of Greenlands Quarry (see above; Fig. 15) that the entire fossiliferous sequence represents deposition during a relatively short interval, coinciding with the climatic and sea-level optimum.

It is worth recording, while considering the palaeobotany, that a number of charophytic oogonia were noted in the vertebrate sample from a sand lens within Bed 4 in the Greenlands Quarry west face, as well as from many of the ostracod samples (Table 5). These represent the calcified fruiting bodies of Charophyta, a small group of fresh- and brackish-water algae (Peck, 1946).

HS1 samples: Bed 8ii

Samples of what is here designated Bed 8ii were examined as part of the preliminary assessment of the HS1 footprint at Purfleet (Project ARC THPE 94), including attempts to extract subfossil pollen (Scaife, in URL, 1995, in Bates et al., 1999). Just a single level was productive: 2001TP, monolith 8, depths 0.32–0.33 m (Context 112). A preliminary count of 100 grains (spores omitted) revealed a range of thermophilous taxa, dominated by those from mixed deciduous woodland, notably *Quercus*, *Corylus avellana* type, *Tilia*, *Fagus* and the aquatic *Myriophyllum alternifolium* (Table 7). This was regarded as tentative evidence of a freshwater interglacial environment, of considerable importance, given the stratigraphical position so high within the Purfleet sequence. Several attempts to repeat the successful extraction of pollen from this bed eventually bore fruit; from five samples from bed 8ii in ARC PFC 01 3957TT (Fig. 7, monolith 5791) just one contained small numbers of pollen (<500 grains ml^{-1}). This was a single sample from a depth of 0.35 m, consisting of a grey silt lamination that contrasted with the generally yellow brown, oxidized sediment of this bed. A count of 140 grains was made (Table 7), which is comparable with the earlier data from this sedimentary unit, concurring with interpretation as a fully interglacial environment.

This information provides a level of support for the suggestion (above) that this bed is an interglacial deposit that accumulated under fluvio-estuarine conditions. Scaife (in URL, 1995), realising the importance of the record, considered in some detail the possibility that the spectrum resulted from Holocene contamination. He concluded that this was unlikely, given the depth of the sample location and the presence of the aquatic *M*. *alternifolium*. In the more recent analysis the presence of sedges (Cyperaceae) and algal *Pediastrum* cysts are further indicators of a freshwater depositional habitat. A mixed deciduous woodland of temperate character is suggested, with oak (*Quercus*) and hazel (*Corylus*) the main constituents, perhaps with lime growing on the interfluves. Alder (*Alnus*) is evident as adjacent floodplain woodland in only one of the two spectra. The palynology can therefore be added to the occurrence of rootlet trace fossils (see above) and to the sedimentology, as evidence that Bed 8ii, and thus Beds 6 and 7, are part of the interglacial MIS 9 sequence at Purfleet.

Comparison with other MIS 9 palynological records

Determinatiion of the age of Middle Pleistocene interglacial sequences on the basis of their contained pollen spectra is now regarded as problematic (cf. Thomas, 2001), with continuing debate on the separation of the MIS 11 and MIS 9 temperate phases (Roe 1995, 1999; Roe et al., 2009, 2011). Sites in the Thames–Medway region are of particular importance, since representation of MIS 9 has been demonstrated here more readily that elsewhere in Britain, thanks to the framework provided by the river terrace sequence (cf. Bridgland, 2000, 2010; Bridgland et al. 2004). On that basis Bridgland (1994) attributed interglacial deposits within the Corbets Tey Formation of the Lower Thames to MIS 9, including those at Stoke Newington, Belhus Park, Purfleet and Grays (Little Thurrock). Further downstream, in Eastern Essex, he attributed interglacial channel-fill deposits at Shoeburyness, Rochford, East Canewdon and Burnham-on-Crouch to MIS 9 on a similar basis. The site at Cudmore Grove, East Mersea, was attributed to MIS 11, however, on the grounds of its similarity to the Clacton Channel deposits (cf. Bridgland et al., 1999). That site has subsequently been established as prepresentative of the Blackwater–Colne tributary system and re-assigned to MIS 9 (Bridgland, 1995; Roe, 1995; Roe et al., 2009), thus providing one of the more complete vegetational sequences from that episode, albeit fluvio-estuarine and therefore of modest resolution. Another site in eastern Essex that has seen detailed pollen work undertaken is Barling, near Southend-on-Sea (Bridgland et al. 2001); with Cudmore Grove this provides the clearest and most detailed pollen sequence attributable to this post-Hoxnian temperate phase. There are similarities exist between the Purfleet pollen record and the better preserved assemblages from Cudmore Grove and Barling. They include the importance of *Pinus* at all three sites, with small numbers of *Abies* and *Picea*. The early temperate stage at Cudmore Grove is characterized by *Quercus*, with *Alnus* and *Corylus*; a similar situation applies at Purfleet. However, occasional *Abies*, considered an important marker for the late-temperate substages, is found at Purfleet and Barling but not in the lower sequence at Cudmore Grove. That might imply a later age within the late temperate substage for Purfleet; the sequence at Barling, with an important *Betula* component, is suggestive of an earlier, pre-temperate phase, entirely pre-dating the Purfleet Bed 4 sequence.

5. PALAEOLITHIC ARCHAEOLOGY

Palaeolithic artefacts, many from stratified deposits, were found in all phases of the HS1 work. This new material, together with that from the Armor Road and Greenlands West Face projects, has been quantified by trench and geological unit (Table 8). It provides a significant addition to the collections already amassed from the Purfleet area. The totals (also including late prehistoric material from overburden and soil), supplemented by those from other existing collections (Roe, 1968; Palmer, 1975; Bridgland, 1994; Bridgland et al., 1995; Schreve et al., 2002; N. Ashton pers. comm.), are classified, as far as possible, according to the stratigraphical sequence of Schreve et al. (2002), as used in this report (see Bed No. in Table 8).

Material with characteristics of Levallois flaking technology was especially prevalent from the base of undifferentiated Bluelands/Botany Gravel (Bed 6/8), immediately adjacent to the Pleistocene river bank. Previous records (A.J. Snelling, in Wymer 1968; Wymer, 1985; Schreve et al., 2002) suggest that such material is confined to the Botany Gravel, so its very presence might be regarded as a means of distinguishing that deposit. Worked flint from Palaeolithic contexts elsewhere along the HS1 at Purfleet is relatively scarce, reflecting the prevalence of section-cleaning operations rather than area excavations (cf. Palmer 1975, Schreve et al., 2002). Variations in excavation methodology have undoubtedly influenced artefact recovery and spatial patterning, as demonstrated at Armor Road, wherejust two artefacts were recovered from the section through the Botany Gravel, whereas 46 came from the area excavation

Condition

The Palaeolithic artefacts were primarily in a sharp to slightly rolled condition with a light orange stain, characteristic of Palaeolithic material that has been reworked and winnowed by fluvial action, offering little potential for refitting. It is typical of artefacts collected previously from Purfleet (Wymer, 1968; Schreve et al., 2002) and indicates that, although no material survives in a primary context, most has not moved far from its place of manufacture. A small number of pieces are more heavily rolled and were probably derived from further afield.

Microdebitage

All phases of recent work at Purfleet have included a comprehensive sieving strategy to recover smaller artefacts, especially microdebitage. All sieve residues produced ‘chips’, although very few represented unequivocal by-products of Palaeolithic flaking. Such material is now considered likely be produced by clast collision in fluvial environments and, following examples from a succession of authors (Warren, 1920; Bridgland and Harding, 1993; Schreve et al., 2002), has been omitted from the analysis.

5.1 Stratigraphy of the Palaeolithic material from Purfleet

Little Thurrock Gravel (Bed 2)

The greatest number of artefacts from Bed 2 comes from the west face of Greenlands Quarry. The technology is characterised by hard-hammer percussion from migrating-platform cores (Fig. 21.1), as has been recognized previously at Purfleet (see White and Ashton, 2003) and is often associated, although not exclusively, with Clactonian assemblages.

Similar material and technology, including a core made on a fragment (Fig. 21.2), come from Bed 2 in Trench 3954TT (Fig. 11). Retouched material includes a probable end-scraper made on a naturally backed flake (Fig. 21.3) and a flake with a flaked notch (Fig. 21.4). Raw material appears to have been obtained from the gravel.

Three of the flakes from Bed 2 in 3953TT (Fig. 12) were of uncertain human workmanship and the other undiagnostic. Similarly four of the flakes from the basal context (Oiv) in the Armor Road section, synonymous with Bed 2, are of uncertain manufacture and may not be artefacts. None of the material from this bed showed any sign of Acheulian technology.

Beds 3–5

No worked flints were recorded in HS1 sections in the interglacial Shelly Gravel (Bed 3) or the laminated clayey silt (Bed 4). All but two of the artefacts from the chalky gravel of Bed 3 (Context Oii) in the Armor Road section (Fig. 14) were possible products of gravel collision and neither of the remainder demonstrated unequivocal Clactonian attributes. The four hard-hammer flakes from lobes of chalky slope deposits interbedded with Beds 3 and 4 towards the southern end of the Greenlands Quarry west face (Fig. 15) were in sharp condition. Whether they date from the interglacial or were incorporated into the slope deposits from an earlier sediment or surface cannot be determined, although they would not be out of place amongst the Clactonian assemblage from Bed 2.

The Bluelands/ Botany Gravel (Bed 6/8)

The decalcified clay–silt (Bed 7) was missing from the HS1 alignment, the west face of Greenlands Pit and the Stonehouse Lane excavation, its absence from these units making it impossible to distinguish the Bluelands Gravel (Bed 6), with its reputed mixed Clactonian and Acheulian (hand-axe) industries, from the Botany Gravel (Bed 8). All remaining artefacts from HS1 were therefore assigned to undifferentiated Bluelands/Botany Gravel (Bed 6/8). The Bluelands Gravel (Bed 6) was nevertheless confirmed not only as the most prolific source of material in the Armor Road extension section but also as a source of Acheulian material, including a pointed hand axe and soft-hammer hand-axe thinning flakes but no apparent Levallois technology (Table 8; see Appendix V, online supplement).

The basal parts of the undifferentiated Bluelands/Botany Gravel, together with involutions in the underlying Chalk surface (also extending beyond the feather-edge of the gravel: see below), were the source of the greatest density of artefacts from the HS1 alignment (Table 8, 3982TT; ARC 310 T02 = watching brief; 2004TP; 3957TT). This concentration, extending approximately 500 m east of Botany Pit, is a continuation of that found in the east face of the pit by A.J. Snelling (in Wymer, 1968) near the base of the gravel, above a rising Chalk surface, at ~13 m O.D.

Artefacts were also collected from the undifferentiated Bluelands/Botany Gravel in the west face of Greenlands Pit, from involutions filled with Bluelands/Botany Gravel at approximately 12 m O.D. in the McKellar's section (3962SE; Fig. 13) and from well-bedded gravel and the fill of an involution (Fig. 10) in 3955TT, also at 12 m O.D. The material from 3962SE included a Levallois core from talus at the base of the section. Worked flint was scarce in the Bluelands/Botany Gravel in all sections further from the chalk valley-side.

The Botany Gravel (Bed 8) could be clearly distinguished at Armor Road, where the area excavation yielded four flakes that were unarguably Levallois end products.

Material from chalk solution/cryoturbation structures (periglacial involutions)

The upper surface of the Chalk, beneath the homogenized overburden in 2004TP (see above; Fig. 1), trial trench 3957TT and as recorded in the watching brief beyond the feather-edge of the Bluelands/Botany Gravel, south-east of 3957TT (Fig. 4), was markedly cryoturbated, with gravelly silt-filled involutions (Fig. 7), not clearly representative of the Bluelands/Botany Gravel. An element of chalk solution was also apparent, however, in the formation of these features. They produced hand axes and Levallois technology (Table 8), including a Levallois core from an involution in 3957TT. This material was in a sharp to rolled condition. Hand axes from the deformation features were more prevalent than cores; however, in all other aspects of composition, technology and morphology, material from these features is similar to that from the Bluelands/Botany Gravel, suggesting broad equivalence. The material from the deformation fills has therefore been analysed with the collections from the base of Bluelands/Botany Gravel in 3982TT and the watching brief.

5.2 Technology

Flakes

Flakes from the Bluelands/Botany Gravel in the HS1 sections were principally of local nodular flint, but also included two of Bullhead flint and seven of marbled flint. Basic metrical and technological analysis of unbroken flakes confirms derivation from preparation and shaping of cores, including Levallois cores, and hand axes. There is a correlation between larger artefacts and material recovered from the mechanical excavator bucket during the watching brief.

The assemblage typifies large-scale industrial activity, using ‘bold’ flaking of large nodules, direct percussion and hard hammers to prepare cores, produce large flake blanks and rough out hand axes. Percussion was directed to a point well back from the front of the core, without platform abrasion or faceting. Relict flake scars rarely exceed one or two removals and never more than four, which are generally parallel to or adjacent to the axis of flaking; this is a recurrent feature of Levallois flakes from Botany Pit at Purfleet (White and Ashton, 2003). The apparent lack, but not complete absence, of soft-hammer thinning flakes from this and previous studies questions whether comprehensive hand-axe thinning was undertaken elsewhere or whether the flakes resulting from that activity were dispersed by water. The occurrence of a hand axe from 3955TT, made on a flake, suggests that the nodules at Purfleet provided ample opportunity for producing large flake blanks of suitable size for hand-axe production.

Cores

Sixteen cores (Table 8, 3982TT, ARC 310 T02, 3957TT) were collected from involutions in the cryoturbated chalk surface (Fig. 22.1) and/or from the base of the Bluelands/Botany Gravel (Figs 22.2–3 and 23.1–2). The principal characteristics of fifteen cores have been tabulated (Table 9) and broadly classified using the technological approach adopted by White and Ashton (2003) in their analysis of 268 cores from the Snelling collection from Botany Pit, now in the British Museum. They applied six criteria defined by Boëda (1995) to identify core reduction strategy, including Levallois technology. The results of their study classified three basic operational schemas to describe the core assemblage: migrating-platform (49%; Fig. 22.1), ‘proto-Levallois’ (43%; Fig. 22.2–3, 23.1–3) and discoidal (8%; Fig. 23.3). The analysis of the HS1 cores (Table 9) shows remarkable similarities in terms of frequency, type and technology in comparison with the much larger Snelling collection.

The results indicate that the ‘proto-Levallois’ cores consistently conformed to all criteria of Boëda’s (1995) technological attributes, with the exception of criterion 3, management of the lateral and distal convexities to predetermine the shape of the resulting flake. Flaking involved the creation of a distinct striking platform, with relatively steep flaking angle, and a separate flaking surface from which a sequence of predetermined invasive flakes could be removed down the long axis of the core. This is similar to the bifacial strategy often used to prepare and shape a nodule in the early stages of hand-axe manufacture, before thinning. Striking platforms could have been re-faceted or a separate flaking surface constructed from an adjacent edge or at the back of the core to prolong flake production. The survival of failed and partly roughed-out implements and cores raises the possibility that some successful cores were removed from the site.

Most of this material was recovered from the Bluelands/Botany Gravel; however a broken single-platform ‘proto-Levallois’ (cf. Wymer, 1968) flake core and a semi-discoidal core, both with prepared striking platforms, were found during the watching brief in involution fills at the south-eastern end of the cutting. In addition to the core from an involution in 3957TT, mentioned above, a discoidal flake core (Fig.23.3) found in the fill of the possible dene-hole in that trench (Fig. 7; Table 8) is also likely to have been derived from the gravel–chalk interface.

An additional unstratified unipolar ‘proto-Levallois’ core (Fig. 23.4) with prepared striking platform was found in spoil at the base of the McKellar section. It was unquestionably from the basal Bluelands/Botany Gravel (perhaps in solution/cryorturbation features) and confirms the distribution of Levallois technology to the north of Botany Pit.

Hand axes

Six pointed hand axes (Fig. 24.1–2) were recovered from the solution/involution fills beyond the Bluelands/Botany Gravel feather-edge in 2004TP and 3957TT (Figs 1 and 7) and during the HS1 watching brief. Five were roughed out and shaped using hard-hammer percussion; of these, three were abandoned due to thermal flaws in the flint. Only one implement, from 2004TP, was thinned using a soft hammer. Two more unfinished hand axes, one of Bullhead flint, were recovered from the base of Bed 6/8 during the watching brief (see above).

Two hand axes were found in 3955TT: one in gravel-filled involutions underlying the Bluelands/Botany Gravel, the other in the body of the gravel. The former, a cordiform (Fig. 24.3), is unfinished, made of marbled flint and in a similar, slightly rolled, condition to the material from the deformation features at the edge of the Bluelands/Botany Gravel. The latter (Fig. 24.4) is pointed, in a rolled condition and made on a flake. It has already been noted that nodules at Purfleet were probably large enough to produce flakes of sufficient size for hand-axe production; however the condition, the choice of blank and the fact that this implement is finished raise the possiblity that it is derived and unrelated to the industrial material. A hand-axe thinning flake was also found in gravel filling an involution beneath the Bed 6/8 gravel in 3955TT.

5.3 Interpretation

The assemblages from the Corbets Tey Formation at Purfleet can be included amongst a very few in the British Lower Palaeolithic that arguably demonstrate a chronological sequence of superimposed well-dated, independent stone-tool technologies. Furthermore, Purfleet is unique in reputedly having a tripartite sequence, defined by a flake-based Clactonian, a core-tool Acheulian and prepared-core Levalloisian (Wymer, 1985): modes

1, 2 and 3 (Clarke 1969) in superposition. The site is therefore crucial in any discussion relating to the development, chronology or reappearance of stone-tool industries in Britain. The status of the Clactonian has been especially hotly debated (McNabb, 1992; Ashton et al., 1994a,b; McNabb and Ashton, 1995; White, 2000), being dependent on the absence of hand axes or by-products (thinning flakes) of hand-axe manufacture, as much as by the presence of hard-hammer percussion from cores using alternate flaking or migrating platform technology. Conversely, the presence of the latter is not conclusive evidence for the presence of Clactonian, as it is a technology commonly used in most forms of core and core-tool preparation.

Opinion currently accepts the existence of an independent flake-based Clactonian industry, although the dispute continues regarding its existence at Purfleet (McNabb, 2007). This debate is stimulated by what is still a relatively small stratified artefact assemblage, despite numerous systematic campaigns of research. Much of the site chronology is based on the limited presence or, in the case of the Little Thurrock Gravel, absence, of diagnostic artefacts, such as hand axes, hand axe thinning flakes or products of Levallois technology. Nonetheless, the patterns of technology and composition, including a low incidence of retouched material, are consistent with a Clactonian interpretation (Table 8). The intermittent distribution makes it possible that discrete artefact scatters occur along the full length of the Purfleet anticline in the Little Thurrock Gravel. It has not been possible to plot horizontal artefact distribution in detail within this deposit but artefacts were apparently more prevalent from the edge of the terrace deposits in the west face of Greenlands Pit and thinned away from this edge, to the north (Fig. 15). The general condition of individual artefacts from the lowermost deposits at Purfleet suggests that horizontal dispersal was relatively localized and that they were derived from short-term occupation by relatively small groups at the edge of the floodplain. The exploitation of fresh flint appears not to have been a significant factor in the occupation of Purfleet at this time. As at Swanscombe (Ashton and McNabb, 1996) and Little Thurrock (Bridgland and Harding, 1993), nodules of flint from the river bed, including marbled and Bullhead flint, were exploited for raw material.

The stratigraphical and chronological sequence at Purfleet (Palmer, 1975; Schreve et al., 2002; Bridgland et al., 1995) has been compiled primarily from sections located near the valley-side edge of the terrace, where traces of early settlement might be concentrated, towards the eastern end of the anticlinal ridge. As well as in the Little Thurrock Gravel, flakes with Clactonian attributes were identified by Schreve et al. (2002) in the 'coombe rock' (Bed 1), at approximately 7 m O.D., and in Beds 3 and 5 above the Little Thurrock Gravel, although in these cases the assemblages were very small and the absence of Acheulian material should not be taken as definitive. Nonetheless, the absence of hand axes and thinning flakes below the Bluelands Gravel would appear to substantiate the idea of an independent Clactonian industry marking the early part of the MIS 9 Interglacial.

The relatively productive Bluelands Gravel is the first deposit within the sequence to yield Acheulian material (Schreve et al., 2002). Regrettably, since this gravel could not be identified individually or separated from the Botany Gravel in the HS1 sections or the west face of Greenlands Pit, it is impossible to trace the Acheulian industry in the Bluelands Gravel beyond the immediate north-east Greenlands–Bluelands area at Purfleet or to confirm whether it has major chronological significance or is merely an isolated occurrence; nonetheless, the excavations at Armor Road, newly reported here, have confirmed the presence of Acheulian material in the Bluelands Gravel (cf. Fig. 14).

Schreve et al. (2002) tentatively upheld the proposal by Wymer (1985) that Levallois technology was present only in the Botany Gravel, but could add little to confirm the presence of Levallois technology at Bluelands or Greenlands pits. Most of the worked flint they recovered was from the Bluelands Gravel, which contained Acheulian material; however two cores reminiscent of the ‘proto-Levallois’ technology normally associated with the Botany Gravel also came from this deposit (M.J. White, in Schreve et al. (2002, p. 1452). These cores hint that embryonic Levallois technology was being adopted by the time the Bluelands Gravel was emplaced, possibly in response to a need to work challenging raw material. White and Ashton (2003) considered it most likely that the Botany Pit hand axes pre-dated the introduction of Levallois technology and were related to the hand axes found in the earlier Bluelands Gravel to the east. However, results from the HS1 project suggest that, at the west end of the anticline, hand-axe making and proto-Levallois technology coexisted. Hand-axe rough-outs and cores produced using proto-Levallois technology were found together at the base of the Bluelands/Botany Gravel and in the deformation features filled with that deposit (see above). Significantly the Armor Road section produced unequivocal evidence that fully fledged Levallois technology is present within the Botany Gravel, in contrast with the proto-Levallois material (described by White and Ashton, 2003, as ‘technologically underdeveloped’) from Botany Pit, approximately one kilometre further west (cf. Wymer, 1968).

The recent results from the west face of Greenlands Pit and from the HS1 sections have extended the distribution of stratified archaeological and palaeoenvironmental material approximately 1 km further west along the north face of the Purfleet anticline and made it possible to compare assemblages in more detail from both ends of the ridge and away from the edge of the river-terrace outcrop. This has served to establish the presence of Levallois in the uppermost sediments over a lateral distance of c. 1.4 km between the McKellar section and Armor Road (Fig. 1) and has failed to find anything to dispute the Clactonian interpretation of the material from the lowest deposits.

The character of activity at Purfleet is reminiscent of human behaviour elsewhere in the Thames and Medway valleys. At Frindsbury, Kent, a poorly dated cluster of freshly worked flint, including refitting flakes and using a technology identical to that at Purfleet (White and Ashton, 2003), was recovered from a hollow exposed in the side of a chalk quarry overlooking the Medway (Cook and Killick, 1924). The site appeared to represent a relatively short-lived industrial activity exploiting raw material in a location, like Purfleet, on a bend in the river and therefore affording a vantage point for observing game movements.

The extent of flaking activity visible in the Purfleet artefacts, if not the density of the material itself, is immediately comparable with Levallois technology recorded from Crayford, south of the Thames (Fig. 2). There, a series of sites, including individual flaking ‘floors’ with early forms of controlled flake–core technology and hand-axe manufacture, was recorded over a lateral extent of over 700 m along the chalk valley-side (Spurrell, 1880; Chandler, 1916). Similarly at Northfleet, Kent (Fig. 2), as a result of extensive quarrying, one of the richest Middle Palaeolithic sites in Britain has been traced for several hundred metres along the tributary valley of the Ebbsfleet (Wenban-Smith, 1995). Finally, a short distance downstream from Purfleet, at West Thurrock, Essex (Fig. 2), a Levallois industrial assemblage again occurs in a terrace-edge context (Bridgland and Harding, 1994, 1995; Schreve et al., 2006). All three of these comparative Lower Thames sites, however, belong to the next terrace in the Lower Thames sequence, formed by the Mucking Gravel (Fig. 3), in which Levallois material is a notable component of the basal deposits (Bridgland, 1994, 2006). Despite the clear chronological differences indicated by the assemblages from the Mucking Formation and the Botany Gravel, the artefact composition, comprising debitage, cores and failed implements, indicates consistent patterns of human behaviour characterized by intensive industrial activity. This is likely to have involved repeated visits over a considerable timespan, with site selection influenced in each case, as at Purfleet, by the availability and exploitation of fresh flint from a valleyside. This approach to the flint resource based on fresh material from the Chalk, as contained in the uppermost deposits at Purfleet, marks a notable contrast with the thinly spread, small-scale flake production from derived nodules in the Little Thurrock Gravel, at the base of the sequence.

6. ANALYSIS OF CARBONATES

The Thames terrace deposits at Purfleet have long been known to contain a range of carbonate precipitates, in particular concretionary overgrowths of pebbles and fossils in the basal interglacial deposits, the fossiliferous gravel of Bed 3 (Schreve et al., 2002). In the absence of any systematic study of these to date, little is known of their mechanism of formation or any other geological information they might contain. Thus examples from the HS1 excavations and the local quarry exposures were investigated in terms of morphology, micromorphology and geochemistry; in particular the stable oxygen and carbon isotopic composition of the carbonates was analysed, as this can frequently yield important palaeoenvironmental information.

The carbonates comprise discrete, spherical–ovoid-shaped concretions up to 15 cm long (Fig. 23). They are not densely cemented and can easily be broken down into powder. X-ray diffraction (XRD) whole rock analysis of these carbonates has shown that the cement is calcite, with no evidence for more complex carbonate minerals (such as dolomite or aragonite). Their powdery nature suggests unsuitabilty for U-series dating, as does their common iron staining, implying infiltration by later iron-rich groundwater, a process that will typically remove or add uranium.

Thin sections of three carbonate concretions, made using the crystic resin impregnation technique of Lee and Kemp (1992), showed a relatively consistent internal structure, comprising a detrital-grain core that has acted as the nucleus for the precipitation of up to 4 cm of secondary carbonate: a bivalve shell fragment in each case (Fig. 26). The secondary carbonate precipitation, generally thicker on one side than the other, is primarily composed of fine-grained calcite microspar, imparting a ‘muddy’ texture to the cement. There is weakly developed lamination in the form of thin bands of coarse spar cement within the overall microspar matrix, forming laminae <1 mm thick, parallel to the surface of the shell core but not continuous for more than 1 cm. Also significant is orange–brown staining in cloudy zones throughout the secondary carbonate, indicating the precipitation of iron oxides.

These characteristics are typical of oncoids (Riding, 1991), which are clasts of secondary carbonate that form as a result of precipitation around a nucleus within a freshwater or marine environment (Esteban and Klappa, 1983; Riding, 1991). They are common in riverine tufas; indeed, they can be considered as mini-tufas. Most researchers regard microbial communities living on the surface of these clasts, particularly photosynthetic cyanobacteria, as essential in oncoid development (Riding, 1991; Andrews et al., 1993; Shiraishi et al., 2008). The photosynthetic activity of these microbial communities leads to the uptake of dissolved CO_2 from the water body, reducing the pH of the water. This leads to supersaturation of carbonate and its consequent precipitation as a solid on and around the clast surface, resulting eventually in the accretion of a thick carbonate coating around the detrital grain core.

There are several features relating to oncoid development that are important for understanding the sedimentation of Bed 3 at Purfleet. First, as carbonate precipitation in oncoids is driven by photosynthetic activity, the water body at Purfleet must have been relatively clear, with a low suspended-sediment load (Riding, 1991). Second, for oncoids to have formed, the river bed and its sediment substrate must have been relatively stable, with low rates of sediment deposition and erosion. Rapid sedimentation rates would have buried the oncoids as they were beginning to form, preventing the accumulation of such substantial carbonate overgrowths. Conversely, erosion of the channel-bed sediment would have stripped the clasts out of the system and removed them before well-developed overgrowths formed. This is not to say that there was absolutely no sediment movement during the formation of the Purfleet oncoids, as many authors have suggested that clasts need to be turned over regularly to allow formation of the all-enveloping coatings that characterize these carbonates (Hagele et al., 2006).

In many cases laminations within oncoids have been suggested as reflecting seasonal variations in water conditions; i.e. flow rate, biological activity or geochemistry (Andrews and Brazier, 2005). In such cases the laminations are characterized by a regularly repeating pattern with relatively consistent laminae thickness. This is not the case within the Purfleet oncoids, as laminae occur at irregular intervals and show no consistency in their internal structure or thickness. In oncoids with irregular patterns of lamination, such as the Purfleet specimens, it is more likely that this structure is driven by episodic but irregular events such as droughts or major floods (Andrews and Brazier, 2005).

In north-west Europe tufas are indicative of warm, temperate climates and, therefore, interglacial conditions. This relationship is a function of the dense vegetation cover, active groundwater systems and accelerated biological processes that occur during such periods (Andrews, 2006), all of which increase the potential and rate of carbonate precipitation. Furthermore, during interglacials, river systems are relatively stable with respect to incision and aggradation (Gibbard and Lewin, 2002) and consequently provide stable substrates on which tufa can precipitate and accumulate. Consequently, records of tufa formation are common in the early/middle Holocene (Garnett et al., 2004; Andrews and Brazier, 2005) as well as during the climatic optima of previous interglacials (Boreham and Gibbard, 1995; Preece et al., 2006).

6.1 Stable isotope geochemistry

The secondary carbonate of 15 different concretions from Bed 3, sample 5399 (Fig. 12), was sampled for analysis of stable oxygen and carbon isotope geochemistry, using methodology described in Appendix III (online supplement). The results are shown in Fig. 27 and summarized in Table 10. Both $\delta^{18}O$ and $\delta^{13}C$ show depletion (of ^{18}O and ^{13}C), producing consistently negative values.

Of the considerable literature on the stable-oxygen and carbon-isotope chemistry of tufas (Andrews et al., 1993; Andrews, 2006), relatively little is directly related to oncoids (Hagele et al., 2006). Of particular relevance is recent research on modern oncoids in the River Gipping, Ipswich, Suffolk (I. Candy, unpublished), which has provided datasets that are compared with those from Purfleet in Table 11. The Gipping study indicates that modern carbonate precipitation and oncoid growth is primarily a summer phenomenon, thus providing information primarily on summer environments (unsurprising, since cyanobacterial photosynthesis will be most active during summer months).

The $\delta^{18}O$ composition of freshwater carbonates reflects the $\delta^{18}O$ composition of the groundwater, mediated by temperature and processes such as evaporation (Andrews, 2006). In temperate regions like Britain, the oxygen isotopic composition of groundwater broadly reflects the average annual isotopic composition of rainfall (Darling et al., 2003; Darling, 2004), which is controlled, predominantly, by air temperature (Rozanski et al., 1993; Darling and Talbot, 2003; Darling, 2004). Therefore, although a wide range of factors can be at play, the overriding control on $\delta^{18}O$ composition is temperature.

The $\delta^{13}C$ composition of the tufa reflects the composition of the dissolved carbon dioxide in the groundwater, which reflects soil carbon dioxide inputs and processes such as degassing (Andrews, 2006). The $\delta^{13}C$ composition of the Purfleet oncoids (mean = –8.49, sd = 0.16) is a typical value for freshwater carbonates in a British interglacial (modern River Gipping: mean = –7.73). The heavily depleted values reflect the uptake of light isotopic carbon dioxide as recharging waters migrated though the soil zone en route to the aquifer/river system. A small amount of $\delta^{13}C$ enrichment is likely to have occurred during carbonate precipitation as a result of selective removal of $\delta^{12}CO_2$ from the water body during cyanobacterial photosynthesis.

The $\delta^{18}O$ composition of the Purfleet oncoids (mean = –7.04, sd = 0.24) is comparable with those derived from Holocene freshwater carbonates across southern and eastern England (Andrews et al., 1993); the $\delta^{18}O$ composition of the former is, within analytical uncertainties, indistinguishable from that of the modern oncoids sampled from the River Gipping (mean = –7.02, sd = 0.44). The simplest interpretation of these datasets is that the Purfleet oncoids formed under summer temperature regimes comparable with the present day (mean air and water temperatures for June–August at the River Gipping study site are approximately 17^{o}C).

Despite the close correlation in mean oxygen and carbon isotopic values at Purfleet and the River Gipping, the spread and scatter of the two datasets are very different (see Fig. 28). Whereas the Purfleet dataset forms a relatively tight cluster, that from the Gipping has a wide spread in both carbon and oxygen isotopes. This is most easily explained by the size of the water body; the River Gipping is a small river, 3–4 metres wide and 0.5–3 metres deep, with the volume of flow significantly affected by seasonal changes in precipitation levels and groundwater recharge. The converse implication of this is that the Purfleet oncoids were forming within a relatively large river channel, in keeping with their attribution to the Thames rather than a minor tributary (cf. Schreve et al., 2002).

6.2 Stable isotopic analysis of mollusc shells

Isotope analyses have also been undertaken on the carbonate in molluscan shells from the Esso Sports Field site at Purfleet. The carbonate of freshwater mollusc shells is precipitated from the water in which they formed, thus allowing fossil shells to be used as geochemical proxies from which to reconstruct the chemistry of ancient water bodies. In particular a great deal of research has been focused on the stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic composition of shell carbonate. In a temperate oceanic region like north-west Europe, temperature is the main control on the $\delta^{18}O$ of shell carbonate (Fritz and Poplawski, 1974; Jones et al., 2002; Leng and Marshall, 2004). The $\delta^{18}O$ composition of rainfall, and consequently of surface water bodies, is controlled by the air temperature, as this will dictate the energy available to air mass systems and their ability to carry and transfer water made up of the heavier $\delta^{18}O$ isotope. The temperature of the water body controls the degree of isotopic fractionation that occurs between source water and the final precipitated carbonate. In a region such as Britain, evaporation effects are minimal, as river and lake systems are constantly being recharged by groundwater inputs. The $\delta^{13}C$ composition of a shell is a result of the bio-productivity of the water body within which it forms, as biological activity will control the carbon isotopic composition of the dissolved CO_2 in the water body.

There now exists a relatively large database of isotopic information from shell carbonate spanning much of the last 700,000 years (cf. I. Candy, in Ashton et al., in press). Many of these have been sampled from interglacial deposits with very well constrained temperature reconstructions, allowing changes in stable isotopic composition to be related to controlling environmental conditions such as temperature. Shells from Bed 5 at the Esso Sports Field site and from Greenlands Quarry (samples 1–5 of Schreve et al., 2002) have been analysed, producing data that can be compared with existing isotopic datasets. The aim of this work (for methodology see Appendix III, online supplement). was to provide information on the environmental conditions that existed during the deposition of the shell-rich beds at Purfleet.

The $\delta^{18}O$ and $\delta^{13}C$ composition of the 10 shell samples from the Esso Sports Field are shown in Fig. 29, in comparison with results from five shells from Greenlands Quarry, as well as others from the MIS 9 site at Hackney (Green et al., 2006) and modern-day Thames shells (raw data are shown in Table 12). All isotopic data are relative to the globally used PDB standard (a Cretaceous belemnite). Mean $\delta^{18}O$ values from the Esso Sports Field site are –5.99‰ (standard deviation = 0.1), whilst mean $\delta^{13}C$ values are -1.99‰ (standard deviation = 0.6). These values are relatively consistent with isotopic analysis carried out on shell carbonate from Greenlands Quarry (mean $\delta^{18}O$ = –5.46‰; mean $\delta^{13}C$ = –11.20‰) and Hackney (mean $\delta^{18}O$ = –6.62‰; mean $\delta^{13}C$ = –10.50‰). They are also consistent with the $\delta^{18}O$ composition of shells from the modern-day Thames (mean $\delta^{18}O$ = –5.70‰), although the modern shells appear to have much lighter $\delta^{13}C$ values (mean $\delta^{13}C$ = –14.73‰).

The mean $\delta^{18}O$ isotopic values of the shells from the Esso Sports Field site (–5.99‰) and Greenlands Quarry (–5.46‰) are very similar to those from the modern Thames (–5.70‰). As temperature is a significant control on the oxygen chemistry of shells, the implication is that the fossil shells formed under a temperature regime comparable with that at the present day; i.e., fully interglacial conditions. Salinity also affects the $\delta^{18}O$ of the water; the evidence of a marginal tidal influence at Purfleet, from the presence of noded *Cyprideis torosa* (see above), suggests salinity slightly above that of freshwater, which could explain the slightly more positive $\delta^{18}O$ values in comparison with the Hackney locality. The latter, although upstream and thus presumably having lower salinity, was still within the tidal reach, since *C. torosa* was present.

The fossil shells have a $\delta^{13}C$ composition 2–4 ‰ heavier than that of modern shells. A common phenomenon in the British Quaternary, this probably reflects the widespread pollution of modern freshwater systems by hydrocarbons, which have very negative $\delta^{13}C$ values. The mean $\delta^{13}C$ value of the Esso Sports Field site samples is characteristic of shells forming in a free-flowing river system recharged regularly by groundwaters that have formed under densely vegetated landscapes. There is no isotopic evidence for the existence of still or sluggish water conditions during the growth of these shells.

It is possible to discuss the palaeo-environmental implications of these results in more detail by comparison with similar isotopic data from a range of sites. By plotting shell $\delta^{18}O$ values from sites with temperature reconstructions derived from fossil beetles against mean summer temperature it is possible to show how shell isotope chemistry varies with changing temperature. This assumes that the air temperature recorded by the coleopteran-based reconstructions is translated into water-body temperature (an assumption that might need qualification, given the potential role of groundwater recharge of the water body). This plot indicates that shell carbonate $\delta^{18}O$ values become progressively more negative with increasing summer temperatures (Fig. 30). Consequently, shells from very warm interglacials, such as MIS 5e (when mean summer temperatures were up to 5°C warmer than present: Coope, 2001), have strongly negative mean $\delta^{18}O$ values (i.e. –7.30‰ for MIS 5e deposits). The shell isotope data from the Purfleet, however, shows no evidence for temperatures warmer than those of the present day (Fig. 29). However, this is inconsistent with the shell data from the supposedly contemporaneous MIS 9 site, at Hackney Downs. Mean $\delta^{18}O$ values of –6.62‰ from that site suggest a temperature regime ~2°C warmer than present-day conditions. The deposits at Hackney Downs contain a range of palaeoclimatic proxies that indicate summer temperatures in excess of modern-day values (Green et al., 2006). These include the presence of the thermophilous freshwater mollusc *Belgrandia marginata*, currently found no further north than southern France and Catalonia (Keen et al., 1999), fossil coleopteran assemblages that indicate mean temperatures of the warmest month +18 to +19°C (~2°C warmer than present) and the remains of thermophilous aquatic plants such as *Salvina natans* and *Trapa natans*, which require mean July temperatures of at least 18°C (~1°C warmer than present) (Keen et al., 1999). No such proxies have been recognized in the Greenlands Shell Bed (Bed 5) at Purfleet, the source of the analysed shells, but the new record in this report of *Emys orbicularis* (from Bed 4 in the west face of Greenlands quarry) further reinforces the notion that summers during the MIS 9 climatic optimum were warmer than at present (see above).

7. OPTICALLY STIMULATED LUMINESCENCE DATING

Five samples for Optically Stimulated Luminescence (OSL) dating were collected from the Greenlands Quarry west face sections. Pairs of samples were collected from the Greenlands shell bed (Bed 5) and the overlying sand and gravel, with a single sample from a sand lens within Bed 4 (Table 13; Fig. 15). A further sample was taken from the sandy infill of a solution feature exposed near the western end of the north face of the quarry. Sand-sized quartz samples were measured using a SAR OSL technique (Murray and Wintle, 2003). Gamma dose rates were measured in situ, using a portable NaI spectrometer, and beta dose rates were calculated on the basis of NAA determination of U, Th and K content, except for sample X839, for which NAA was used for gamma and beta dose rates. A water content of 5 ± 5% was used for the free-draining sand deposits, whereas a value of 10 ± 5% was used for Sample X839, from the sand lens within the underlying silty interglacial deposits of Bed 4.

7.1 Age estimates

Table 13 shows the dates from the six samples in stratigraphical sequence, with X839 as the oldest sample, stratigraphically (Bed 4), followed by a pairs of samples (X801 and X802) from the Greenlands Shell Bed (Bed 5) and (X803 and X804) the overlying Bluelands/Botany Gravel (Fig. 15). Sample X805, taken from the north face of the quarry, is is from material equivalent to the Bed 9 overburden, deposited later than the fluvial sequence at Purfleet. There is a small age inversion between sample X839 and the overlying sample pairs. It is considered most likely that this represents the systematic effects of a small dose-rate determination error, possibly relating to the reliance of NAA alone for this basal sample. An age estimate of 329±30 ka has been derived for the interglacial deposits, using this basal sample in combination with those from the stratigraphically higher beds.

All of the fluvial samples (i.e. excepting X805) have provided age estimates within the range 405–267 ka (although with error margins extending outside this range), which compares reasonably favourably with the hypothesized age of the Purfleet sequence, MIS 10–8 (Bridgland, 1994; Schreve et al., 2002), although the pre-interglacial MIS 10 deposits were not sampled. The age estimate of 405±27 from sample X801 would place it in late MIS 12, MIS 11 or early MIS 10, a result that appears to be an overestimate; such an age would be more in keeping with material from the highest Lower Thames terrace, at sites such as Swanscombe (see Fig. 3). The next four samples (X802-4 and X839) all gave ages that overlap, at one standard deviation, with MIS 9 (taken to be ~340–277 ka). The age from sample X805 places the solution-hollow infill within MIS 6, a result that is perfectly plausible, given that wind-blown deposits attributed to that cold stage have been recognized elsewhere in the Lower Thames such as at Northfleet (e.g. Bridgland, 1994). All in all, the new OSL data, albeit lacking in precision, provide useful support for the interpretation of the Corbets Tey Formation as dating from MIS 10–8 and for the 'Purfleet interglacial' equating with MIS 9.

8. AMINO ACID DATING: A REVISED METHOD

Previous amino acid studies at Purfleet were based on a method of whole-shell analysis, to obtain the ratio of D-alloisoleucine to L-isoleucine (A/I), described by Sykes (1991). This was applied to molluscan shells from Purfleet as part of a programme of amino acid geochronology established by Bowen et al. (1989) from sites in southern Britain. Their data from Purfleet was problematic, however, in that they obtained higher A/I values than were anticipated for late Middle Pleistocene material: 0.34±24 from *Bithynia tentaculata* and 0.38±07 from *Corbicula fluminalis* shells. Such ratios would have been appropriate for shells from early Middle Pleistocene contexts but within the Lower Thames sequence they represented an anomalous dating inversion, since they were higher (older) than ratios from Swanscombe, in the higher Boyn Hill/Orsett Heath terrace (Fig. 3). Developing the dataset further, and using the Lower Thames terrace sequence as a template, Bowen et al. (1995) were able to cite a more appropriate ratio for the MIS 9 deposits within the Corbets Tey Formation, although the majority of the Purfleet ratios obtained using this method remain problematically high.

A refined methodology for amino acid dating has been developed (Penkman, 2005, 2009; Penkman et al., 2007; 2008a, 2010) that allows the distinction between amino acids within the crystalline structure of shells and both inter-crystalline and exogenous amino acids. These 'intracrystalline' amino acids behave as a closed system; they are less susceptible to post-mortem contamination and leaching, both of which would compromise their utility for dating. Restricting the analyses to the better-conserved intra-crystalline amino acids means that data from the two methods are not directly comparable. The new method of analysis, using Reverse Phase High Pressure Liquid Chromatography (Kaufman and Manley, 1998), also allows the resolution of the L- and D- isomers of multiple amino acids.

A particularly promising development of this dating technique as applied to freshwater Mollusca has been its use for intra-crystalline amino acids within the calcite opercula of *Bithynia tentaculata*, from which a sizeable database of ratios has been assembled

(Penkman et al., 2010, 2011). These opercula have been found to provide better quality data than that from aragonitic shell, particularly at older sites and from deposits where post-depositional diagenesis has occurred, such as at Purfleet (Penkman et al., 2007; 2008b). Analyses were undertaken on nine individual *B. tentaculata* opercula from Bed 3 in HS1 exposures: three from Section 108 (Sample 272; Fig. 6): NEaar 4824-26, termed HS1P1; three from 3953TT (Sample 5399; Fig. 12): NEaar 4827-9, termed HS1P2; and three from the Starland section (Sample 515; Fig. 6): NEaar 4830-36, termed HS1P3. Methodology was described in detail by Penkman et al. (2008a; see also Appendix VI, online supplement), with two subsamples taken from each individual shell: one for the analysis of the free amino acids ('FAA'), and the second for the analysis of both the peptide bond and free amino acids (total hydrolysable amino acids; 'THAA'). On the basis of the relative D/L values and concentrations (see Appendix VI, online supplement), all the amino acids from the Purfleet horizons indicate an age older than MIS 7 and younger than the Cromerian. Discrimination between sites at the end of one interglacial from the beginning of the next is difficult, due to the slowing of the protein breakdown during cold stages. Some of the amino acids analysed do not allow discrimination of this Purfleet material from some MIS 11 sites, but the slower racemizing amino acids, such as Glx, point to a younger age (Fig. 31).

In order to provide a useful insight alongside the interpretation based on the graphical data alone, for each amino acid within each fraction (FAA and THAA), a 2-tailed t-test was undertaken, comparing the Purfleet dataset with opercula from the MIS 11 site at Clacton (Penkman et al., in press). The material from Clacton comes from samples correlated with the Lower Freshwater Bed at the West Cliff, attributed to MIS 11 (Bridgland et al., 1999). Along with the problem of the small sample sizes available, amino acid data has upper and lower limits (e.g. 0 and 1 for the D/L data) and therefore statistical tests must be applied with caution. However, a 2-tailed t-test assumes no prior knowledge of the stratigraphy of the sites, therefore providing a useful guide of the resolving power of this technique when applied to sites of unknown age. The test assumes unequal variances and a normal dataset, previously found to be valid for opercula data. If the result of the t-test produces a $p<0.05$, this enables discrimination between the two sites at a 95% confidence level (Table 14). It can be stated (within 95% confidence limits) that 28 out of the 30 indicators of protein decomposition in the *Bithynia* opercula demonstrate more extreme protein decomposition at Clacton, with two not able to discriminate between the two sites. The data from the opercula therefore strongly support the hypothesis that the age of Purfleet is significantly younger than the MIS 11 site at Clacton and is therefore consistent with a correlation with MIS 9.

9. SYNTHESIS: AN IMPROVED RECORD OF THE MIS 9 INTERGLACIAL IN THE LOWER THAMES

The dating and palaeo-environmental evidence presented above serves to reinforce the view that the interglacial sediments within the Corbets Tey Formation at Purfleet represent MIS 9. This interpretation conforms with the attribution of the sites at Grays, Barling, Cudmore Grove and Hackney to this same marine isotope stage (cf. Bridgland et al., 2001; Schreve, 2001; Green et al., 2006). As has been mentioned above in connection with some of them, these share biostratigraphical characteristics with Purfleet and fall within the same terrace formation (Cudmore Grove belongs to a north-bank tributary of the Thames–Medway: see Bridgland et al., 2001). This view is in harmony, too, with the growing consensus that the first post-Anglian interglacial in Britain, the Hoxnian, occurred during MIS 11, as reiterated recently by Preece et al. (2007). They applied U-series, thermoluminescence and AAR dating techniques to Hoxnian sediments at Beeches Pit (West Stow, Suffolk) and derived age estimates that support assignment to MIS 11. That first post-Anglian interglacial is represented in the Lower Thames sequence by sites in the highest terrace, formed by the Boyn Hill/Orsett Heath Formation (Bridgland, 1994, 2006; Fig. 3).

There remains an element of controversy, however. Some workers, particularly in the Netherlands and Germany, persist in a view that the Elsterian (=Anglian) Glacial equates with MIS 10 (Zagwijn, 1996; Geyh and Müller, 2005; cf. Preece et al., 2007). Those holding this view envisage a correspondingly younger MIS correlative for the first post-Elsterian interglacial, the Holsteinian (=Hoxnian): rather than MIS 11 they attribute this to MIS 9 (Geyh and Müller, 2005; cf. Scourse, 2006). Interpretation of the Lower Thames terrace sequence, in which there is sedimentological and palaeontological evidence for four separate warm-climate events of fully interglacial status (Bridgland, 1994; Schreve, 2001; Bridgland and Schreve, 2004; Fig. 3), provides an important basis for supporting the 'longer' of these two chronologies. Added to this, and to the geochronological evidence from Beeches Pit, are results from uranium series dating of the Hoxnian type locality at Hoxne and the paratypesite at Marks Tey, Essex (Grün and Schwarcz, 2000; Rowe et al., 1999), both supporting correlation with MIS 11, and therefore the longer chronology.

Two geochronological techniques have been applied at Purfleet: OSL and amino acid dating. The OSL results are of variable quality but include a core group of four dates that, notwithstanding their relatively high uncertainty bands, are consistent with an age in MIS 9. This is particularly the case when the palaeo-environmental evidence for a warm climate is taken into account, since it precludes those areas of uncertainty that stray into MIS 10 and 8. A similar reasoning can be used to reject one of the dates that clearly overestimates the age (see above). Thus the OSL results provide good evidence that the interglacial deposits were laid down in MIS 9, although they cannot place them more precisely than that, unless the full-interglacial warmth indicated by the MOCR data (see above, section 4.3), as well as the indications of a high sea level, can be used to rule out substages of MIS 9 other than 9e (Fig. 32; see below, section 9.3). As noted above, there is strong support for this interpretation from amino acid analysis of *B*. *tentaculata* opercula, with statistical confirmation (at 95% the confidence level) that the Purfleet sediments are younger than those at Clacton, which are attributed to MIS 11.

9.1 Additional biostratigraphical evidence

Schreve et al. (2002) made a robust biostratigraphical case for distinction of a post-Hoxnian, pre-MIS 7 interglacial at Purfleet, attributable to MIS 9. The strongest element of their biostratigraphical argument came from the mammalian evidence (cf. Schreve, 2001), with supplementary data from other vertebrates and from other fossil groups, such as molluscs and ostracods. In many ways Purfleet is the best of the several sites in the lower part of the Thames catchment for which an age in MIS 9 is claimed, not least because of its location in the area of optimal preservation of both faunal evidence and Palaeolithic archaeology, within the Chalk outcrop of the Purfleet anticline. This location is shared with Grays/Little Thurrock (Orsett Road and Globe Pits – Fig. 2), also attributed to MIS 9 (Bridgland, 1994; Schreve, 2001), although exposures there have been limited in recent years (Bridgland et al., 2003).

The present report includes a significant update of the ostracod biostratigraphy, based on better understanding of the systematics of some of the key genera. In particular, two non-marine ostracod species that occur in the Purfleet sediments can be seen to have a potential bearing on their age: *Ilyocypris salebrosa* and *Scottia tumida*. The former occurred in both Section 108 (Sample 103, Bed 4 – Fig. 6) and in 3953TT (Sample 5399, Bed 3 – Fig. 12), and in the latter sample it co-occurred with *Scottia tumida*. Both have restricted age ranges (Whittaker and Horne, 2009). *I*. *salebrosa* is extinct in Britain and north-west Europe. Outside the British Isles it has been recorded under a variety of synonyms in the Middle Pleistocene (Whittaker, in Bates et al., 2002); today it still lives in North America, in the southern part of eastern Europe and in eastern Asia. Of relevance in the present context is that it has been found at Purfleet, Barling and Allhallows: all in the Thames catchment and all potentially attributable to the MIS 9 interglacial. It is also known from the Rhine in coeval sediments (Bates et al., 2002), which may provide evidence that the Thames-Medway and Rhine were confluent at this time. *S*. *tumida* is also extinct and, while it has a longer range (early Cromerian Complex to Purfleet (MIS 9) Interglacial), its youngest record, coupled with a joint occurrence with *I*. *salebrosa*, again firmly asserts a MIS 9 age for the Purfleet sediments. In the Thames-Medway system, *S*. *tumida* is previously known from Barling, Purfleet, Grays (its type-locality) and Allhallows, all sites that have been attributed to MIS 9 (see above).

This report also provides an enhanced pollen record from the laminated silts of Bed 4 (Fig. 20). The use of palaeobotany as a means to date the Purfleet interglacial has been a major source of contention in the past (cf. Gibbard, 1994, 1995a; Schreve et al., 2002). Nevertheless, there are some possible pointers from the HS1 analysis, all new discoveries for Purfleet. In particular *Abies*, well represented in the new pollen diagram (Fig. 20), has been regarded as an important indicator of interglacial pollen spectra from late in Hoxnian interglacial successions (e.g. West, 1956; Turner, 1970; Bridgland et al., 1999), although it has also been recorded from sites in the Thames–Medway system regarded as lateral correlatives of Purfleet, at Barling, Shoeburyness and Cudmore Grove (Bridgland et al., 2001). It also occurs in sediments attributed to MIS 9 in the Axe valley at Broom, Dorset (Hosfield et al., 2011; see above). It is notable that *Abies* is an important component of both the Praclaux and Landos interglacials, recognized in the deep lacustrine sequences of the Massif Central, France, and correlated with MIS 11 and MIS 9, respectively (Reille and de Beaulieu, 1995); it is, however, insignificant in the later Le Bouchet 1 interglacial, which is equated with MIS 7. This suggests that a significant *Abies* component in pollen sequences from the European late Middle Pleistocene might be indicative of the two earlier interglacials and preclude MIS 7. The aquatic species *Azolla filiculoides* has also been associated with the Hoxnian and, like *Abies*, is considered to have been absent from Britain during the MIS 7 and 5e interglacials (Bridgland et al., 2001; Green et al., 2006; Wenban-Smith et al., 2006). It is present, however, in the sediments attributed to MIS 9 at Barling (Bridgland et al., 2001) and Hackney (Green et al., 2006); its record at Purfleet (Fig. 20) is therefore significant.

9.2 New evidence for climatic conditions during MIS 9

A range of evidence for the nature of the environment and climate during the MIS 9 interglacial is now available from Purfleet and the other lower Thames sites attributed to this little-known interval, some of it presented here for the first time. Whereas the earlier MIS 11 interglacial (more intensively studied because of its potential as a Holocene analogue) was relatively lengthy, although perhaps subdued in terms of maximum temperatures and certainly wetter than subsequent interglacials (Droxler et al., 2003; Kukla, 2003; Desprat et al., 2005; Preece et al., 2007), the fully temperate phase of MIS 9 (substage 9e) can be shown to have been relatively brief (Petit et al., 1999; Siddall et al., 2003; EPICA community members, 2004; Tzedakis et al., 1997, 2004, 2009; Fig. 32). Data now available from isotopic study of carbonate nodules and mutual temperature-range estimates from ostracod assemblages point to a climate, during the optimum of MIS 9, with more extreme seasonality and possibly warmer summers than present day. In contrast with the 17,000–19,000 year duration of the MIS 11 interglacial (substage 11e), calculated from annually laminated pollen-rich diatomites in the Holsteinian type area on north-west Germany (Kukla, 2003), and indeed the even longer 32,000-year interglacial recorded from Iberian offshore data (Desprat et al., 2005), the duration of temperate-climate conditions during the warmest part of MIS 9 (9e) was no more than 3,600 years (Tzedakis et al., 2004).

The strongest evidence for palaeoclimate from the Purfleet complex of sites is probably the results of the Mutual Ostracod Temperature Range (MOTR) method presented above. These argue for a palaeo-temperature range between +16 and +21^{o}C for the July average and between -3 and +3 ^{o}C for January. The hint of increased warmth in comparison with the present day is reinforced by the new discovery of *Emys orbicularis* from the west face of Greenlands Quarry (see above) and is in corroboration with Mutual Climatic Range (MCR) data from the MIS 9 deposits at Hackney, which suggest temperatures ~2^{o} warmer than at present (Green et al. 2006; see above). The evidence for greater continentality might bear on the unresolved question of when Britain was first separated from the continent. The idea that the initial formation of the Dover Strait was an indirect result of the Elsterian/Anglian glaciation (Gibbard, 1995b) has been questioned on the bases of faunal impoverishment in the southern North Sea during MIS 11 (Meijer and Preece, 1995; Scourse et al., 1998, 1999) and Palaeolithic artefact distribution (Ashton and Lewis, 2002). Recently further support for later separation from mainland Europe has come from the submarine survey of the English Channel, in particular the freshness of submerged landforms that are attributed to the catastrophic drainage of a post-glacial lake in the southern North Sea, an event that is thought to have formed the Strait of Dover (Gupta et al., 2007). This attribution has been questioned, however, by Westaway and Bridgland (2010). Whether the evidence from Purfleet of greater continentality during MIS 9 is sufficient to suppose that Britain remained a peninsula throughout that stage, or merely reflects the narrower strait that would have existed before the combined effects of coastal erosion during later high-sea-level episodes, is uncertain.

9.3 Matching the Purfleet sequence with global records

Assuming that the correlation between the interglacial represented at Purfleet (and elsewhere in the Corbets Tey Formation) and MIS 9 is correct, there remains the task of establishing a fit between the terrestrial and marine sequences. Notable records of the MIS 9 marine climatic signal come from the North Atlantic margin off the coast of Portugal, where the character of European vegetation has been evaluated from fluvially transported pollen (Abreu et al., 2005; Tzedakis et al., 2009), and from the Red Sea, where the data have been used to establish a sea-level curve (Siddall et al., 2003; Fig. 32). The marine stage includes three warm substages, the first of which (MIS 9e) is most likely to correlate with the estuarine interglacial sediments at Purfleet, since it is indicative of considerable warmth and of a high global sea level, despite its short duration (Tzedakis et al., 2004; see above). It appears from the Red Sea data to correspond with a high-sea-level pulse comparable, within the last 500 ka, only with those of MIS 5e and the Holocene (Fig. 32). The unequivocal evidence for a high-sea-level event within the Purfleet sequence, from the invertebrate assemblages associated with Beds 3–5 and from the sedimentological charateristics of Bed 4 (see above), is thus likely to correspond with MIS 9e. Furthermore, although a substantial hiatus cannot be ruled out completely, there appears to have been continuity of deposition from the cold-climate sediments of Beds 1 and 2 into the rapid warming indicated by the fossil assemblages of Bed 3. Therefore the most parsimonious position for Beds 3, 4 and 5 would be in the first temperate substage, 9e. The palaeontological similarity between Beds 3–5 and the intercalation of these deposits (especially in the Greenlands Quarry, west face: Fig. 15) implies that all the main fossiliferous deposits at Purfleet represent the same episode. Neither the OSL nor the AAR dating is of sufficient resolution to add to this argument, although some of the OSL ages are able, at one standard deviation, to place elements of the Purfleet sequence in appropriate parts of MIS 9 (Table 13).

An important question remains as to whether the stratigraphically younger and less well preserved evidence for warm-climate and possibly estuarine sedimentation at Purfleet also represents this same substage (MIS 9e) or whether one or both of the later substages might be represented. The evidence for either Bed 7 or Bed 8ii being of warm-climate and/or estuarine origin is discussed above; it can only be described as tentative. It is an unfortunate feature of the Lower Thames sedimentary archive, in this and other terraces, that the upper parts of the interglacial sequences are invariably degraded and decalcified; the evidence for the early parts of the marine stages is therefore much better known within this sequence, although the later parts are not necessarily absent. It is to be hoped that improved techniques in future will throw further light on them.

In contrast with the relative richness of sites now attributable to the MIS 9 interglacial in the Thames system (in downstream sequence, these are Hackney, Upminster, Belhus Park, Purfleet, Grays, Little Thurrock, Shoeburyness, Barling and Cudmore Grove; see above; cf. Schreve et al., 2002, figure 15), looking beyond Britain for correlative fluvial sites is somewhat unrewarding. As in the Thames, it has generally required full sequences of terraces containing multiple interglacial records to provide convincing evidence of this under-represented episode. In nearby northern France, such records occur in the Somme and Seine systems (cf. Antoine et al., 2007), where, indeed, sediments attributed to MIS 9 are to be found. In the Seine, near Rouen, these include clayey silts interpreted as estuarine, at a comparable height above sea level (~5 m O.D.) to Bed 4 at Purfleet; in contrast to the Thames, however, further estuarine sediments attributed to MIS 7 occur in superposition within the same sequence (Antoine et al., 2007, figure 2). At Soucy, in the Yonne tributary of the Seine, fossiliferous interglacial sediments have been dated by ESR, providing support for an age within MIS 9 (Chaussé et al., 2004; Antoine et al., 2007). In the Somme, interglacial sediments capping the Epinette Formation, which forms the fourth terrace (counting upwards), have again been dated to MIS 9 using the ESR method (Bridgland et al., 2006; cf. Antoine et al., 2007, figure 5). Artefacts found in association with all these French sites are Acheulian, with Levallois technology appearing in the next terrace within the Somme sequence, representing MIS 8 (Bridgland et al., 2006; Antoine et al., 2007).

Comparably complete late Middle Pleistocene fluvial sequences in Germany provide further examples of MIS 9 riverine sediments, amongst which two are of particular importance: a terrace staircase of the River Wipper, in Thuringia, and a basin-infill sequence exposed in an open-cast lignite mine at Schöningen, Lower Saxony, both of which have yielded notable archaeological assemblages (Mania, 1995; Urban et al., 1995; Bridgland et al., 2006; Mishra et al., 2007). The terraces of the Wipper, a tributary of the Saale–Elbe system, are documented from a single meander-core at Bilzingsleben and include interbedded cold-climate gravels and interglacial travertines, with colluvial overburden, some of it loessic. The travertines, precipitated subaerially, contain well-preserved animal and plant fossils and, in the case of the higher terraces, Palaeolithic artefacts and hominin fossils (Mania, 1995). The travertines within the lower terraces in the sequence, including that thought to represent MIS 9 (Bilzingsleben III: Schreve et al., 2007), have been exposed only in temporary excavations and have as yet yielded no detailed faunal evidence. The channel-fill sediment bodies exposed at Schöningen would appear to represent a partly stacked sequence, in which the order of deposition can be determined from superposition, at least at the channel edges (cf. Bridgland et al., 2006, figure 9). It includes deposits ranging from Holsteinian to Holocene in age but there has been controversy about the attribution of particular channel-fills to late Middle Pleistocene interglacials. Archaeologically the most significant are the Schöningen II channel deposits, to which the name 'Reinsdorf interglacial' has been given; they have yielded several wooden artefacts, interpreted as throwing spears and hafts for stone points (Thieme, 2003). Although widely attributed to MIS 9 (Urban, 1995; Urban et al., 1995), there are mammalian biostratigraphical reasons for considering the Reinsdorf interglacial to be equivalent to the later temperate substage of MIS 11, since the closest match is with the faunas from Bilzingsleben II and Swanscombe (Schreve and Bridgland, 2002; Schreve et al., 2007). Mania's (1995) interpretation is in support of this, since he noted that the palynological evidence from Schöningen II suggests correlation with Bilzingsleben II. The next youngest channel-fill, Schöningen III, has been ascribed to an interglacial named after the site; those who correlate the Reinsdorf interglacial with MIS 9 place this Schöningen interglacial in MIS 7 (Urban, 1995; Urban et al., 1995), whereas Schreve and Bridgland (2002) have argued that it represents MIS 9. They claimed, as supporting evidence, the occurrence of *Azolla filliculoides* (thought to be absent in MIS 7 and 5 in north-west Europe: see above) in the Schöningen III deposits, although Urban's (1995) observation that these sediments lack pollen of *Abies* would potentially support the contrary view, since this species is important at sites in Britain now attributed to MIS 9, such as Cudmore Grove, Barling and, from the present study, Purfleet (see above).

The controversy over the age of the Reinsdorf and Schöningen interglacials extends into the Netherlands, where it is linked to the interpretation of the Maastricht-Belvédère deposits that fall within the Caberg Terrace of the River Maas (Meuse) (van Kolfschoten et al., 1993). Vandenberghe (1995) suggested correlation between the Belvédère interglacial and the early–middle part of the Schöningen interglacial (Schöningen III) and the received wisdom (Vandenberghe et al., 1993) has been that the former equates with MIS 7(e), as with the Urban et al. (1995) interpretation of the Schöningen interglacial. However, a recent reappraisal of Dutch and wider north-west European post-Elsterian temperate-climate fossiliferous sites, based on amino acid analyses of molluscan shells, has led Meijer and Cleveringa (2009) to the conclusion that the Maastricht-Belvédère interglacial correlates with MIS 9. These authors concur with a MIS 9 age for Purfleet, which they therefore correlate with Maastricht-Belvédère, also placing the Holsteinian stratotype at Hummelsbüttel, Germany, in that stage. This would mean that the type-Holsteinian is younger than the British Hoxnian (cf. Schreve, 2001; Preece et al., 2007) and would, instead, correlate with the Purfleet interglacial.

Searching yet further afield produces relatively few results. It is noticeable that many fluvial sequences that have separate terraces representing most of the 100 ka climate cycles have gaps where a terrace dating from MIS 10–9 might have been; in the reviews of well-dated river terrace systems by Bridgland and Westaway (2007a, b) this situation is seen in sequences from around the world, including those of the Dniester (Ukraine–Moldova), the South Platte and the Colorado (USA), the Sundays (South Africa) and the Shoalhaven (Australia). Where terraces that might include MIS 9 components are represented there is often poor preservation of biostratigraphical evidence and scant means for dating, so the age attribution is based solely on mathematical modelling of terrace incision and associated crustal uplift. MIS 9 is recognized from other sedimentary environments, however, amongst which the cave site of Orgnac 3, in the Ardèche region of southern France, is of great significance and relevance to the story from Purfleet, since it represents the earliest appearance of Levallois technology in that region; it is dated by U-series and ESR to 309 ± 34 ka (Moigne and Moncel, 2005). The appearance of Levallois is also thought to occur at around 300 ka in many river systems in central France, on the basis of numerous ESR dates (Voinchet et al., 2005), although correlation with MIS stratigraphy is hampered by the small number of terraces in many of these sequences (Despriée et al., 2005; cf. Bridgland et al., 2006).

9.4 Palaeolithic evidence from the Corbets Tey Formation at Purfleet

As a result of the various projects documented here, more than 350 further stratified artefacts have been added to the archive from the Purfleet locality as a whole. This provides a larger body of material from which to assess the celebrated tripartite Palaeolithic sequence. The modest amount of new Palaeolithic material from the basal gravel (Bed 2) has, as in all the earlier assemblages from this level, nothing amongst it to indicate either hand-axe making or Levallois technology. Thus, from negative evidence, it confirms the association of this deposit with the Clactonian industry, an association that owes much to correlation with the lower, pre-interglacial gravel at Little Thurrock, the site from which this basal gravel is named (cf. Bridgland and Harding, 1993; Schreve et al., 2002). The largest and most valuable new assemblage from Bed 2 is from 3954TT, including characteristic Clactonian flakes, cores and retouched material (Fig. 21.2–4). The Greenlands West Face project has also produced useful new data from this level, including some specimens that are highly characteristic of the Clactonian (Fig. 21.1). Similar material was also found in valleyside-edge deposits interbedded within the interglacial sequence in this section (Fig. 15).

The Armor Road excavations, published here for the first time, are important in that they have confirmed the association of the Bluelands Gravel (Bed 6) with Acheulian hand axes, the middle part of the tripartite sequence. Work at Armor Road also demonstrated the occurrence of artefacts showing unequivocal Levallois technology in the uppermost Botany Gravel (Bed 8) in the area between Greenlands and Bluelands quarries. Unfortunately, however, these gravels could not be separately identified further afield, in the absence of the intervening Bed 7 (see above). Thus the largest body of newly discovered artefacts from the base of the ‘upper gravel’ and its disrupted interface with the Chalk, as revealed in the various HS1 sections (Table 8), cannot be allocated to either the Bluelands or Botany Gravel definitively. A significant proportion of this material shows Levallois technology (Figs 22 and 23), suggesting the presence of the Botany Gravel, although the record of two cores with proto-Levallois affinities from the Bluelands Gravel in Section 2 of Schreve et al. (2002) raises an element of doubt in the distinction of parts 2 and 3 of the tripartite sequence. These two cores are perhaps best explained, however, as pre-emptive Levallois-like technology that was present in the Acheulian in MIS 9, from which the Levallois developed, in which case they do not compromise the tripartite sequence (cf. Harding et al., in press).

The evidence from Purfleet led Bridgland (1994, 2006) to suggest that Levallois technology appeared in Britain for the first time, as represented at this site, early in MIS 8. Westaway et al. (2006) have subsequently suggested that Levallois might appear slightly earlier in the Solent terrace sequence, in deposits thought to represent MIS 9b, a view based on numerical modelling of the fluvial incision recorded by the Solent terraces, using, for calibration, rare biostratigraphical pinning points together with the archaeological record from the sequence as a whole. Two key factors might help determine whether there is evidence from Purfleet of Levallois technology appearing within MIS 9: (1) there are the two cores with ‘proto-Levallois’ affinities from the Bluelands Gravel, mentioned above, and (2) the distinct possibility that one or both of the weathered silt, Bed 7, which separates the Bluelands and Botany gravels, and the high-level laminated silt of Bed 8ii were deposited during the interglacial (see above). Indeed, the possibility that these beds represent a further marine interglacial highstand within MIS 9 allows speculation that they date from MIS 9c and/or 9a and the Bluelands Gravel from MIS 9d or 9b. Thus it is possible that much, perhaps even all of the upper part of the Purfleet sequence, albeit decalcified and therefore lacking faunal evidence, represents the MIS 9 interglacial rather than early MIS 8. In this case the appearance of Levallois in the Thames valley might have occurred during MIS 9, as in the Solent (cf. Westaway et al., 2006). The reader must weigh up the reported evidence for the interglacial origin of Beds 7 and 8ii and assess whether there is genuine support for the arrival of Levallois technology in the Thames valley slightly earlier than previously supposed.

This is an important issue: the adoption of Levallois technology was crucial in the development of early human communities in Europe, marking the introduction of controlled, lightweight, easily mobile and adaptable flake-tool production and moving away from regimented core-tool based technology. Artefacts displaying Levallois traits have been recognized at sites considerably earlier than MIS 9, in the River Somme at Cagney la Garenne (MIS 12/11) (Tuffreau, 1995) and in the Thames at Rickson’s Pit, Swanscombe (Roe 1981) and Bowman’s Lodge, Dartford (Tester, 1950), both representing MIS 11 (Bridgland, 1994; White et al., 1995). However these examples often adapted thick or broken hand axes as supports for the removal of flakes, thus lacking the characteristics of prepared-core Levallois technology (White et al., 2006). The final transition can arguably be seen at Purfleet, where hand-axe making with hints of proto-Levallois core technology in the Bluelands Gravel emerges as fully developed Levallois technology in the Botany Gravel. This trend was not restricted to Britain, but can also be identified in continental Europe, most clearly at Orgnac 3, southern France (Moncel and Combier 1992; Moncel 1996), dated to 350,000–300,000 years ago. Here stone tool assemblages demonstrate a development from one of cores, flakes and flake tools with a few hand axes, in levels 7 and 6, through one with simple prepared cores in level 5 and on to fully developed Levallois in level 4, coinciding with MIS 9–8 (Moncel et al., 2005). Sites dated with less certainty, but nevertheless probably amongst the earliest to reveal Levallois technology in Britain, are documented at Yiewsley and Acton, in west London (Ashton et al., 2003), and Sturry, Kent (Bridgland et al., 1998). Technology similar to that at Purfleet, and of similar (MIS 8) age, has also been described from elsewhere in Europe, including Argoeuves, in the Somme valley (Tuffreau, 1982, 1995), Mesvin IV, Hainault, Belgium (Cahen and Michel, 1986), Maastricht-Belvédère, South Limburg (Kolen et al. 1999; Roebroeks et al. 1992), already identied above as a potentially dating from MIS 9–8, and Markkleeberg in Germany (Baumann and Mania, 1983; Svoboda, 1989), confirming widespread continental development.

The origins of the Levallois technique extend beyond issues of chronology to include those of technology (White and Ashton, 2003) and human behaviour. Many of the sites in Britain and Europe with Levallois technology are in river valleys and are associated with high-energy fluvial deposits. In the Thames, some of the largest worked-flint assemblages, including that from Purfleet and, from the MIS 8–7–6 Taplow–Mucking terrace (Fig. 3), those from Northfleet (Smith, 1911; Wenban-Smith, 1995), Crayford (Spurrell, 1880; Chandler, 1916; Kennard, 1944) and West Thurrock (Warren, 1923; Bridgland, 1994; Schreve et al., 2006), are related to industrial sites adjacent to river cliffs. These have evidence of large-scale extraction and working of flint (workshops), combined with areas of tool manufacture and use (Turq, 1988, 1989). The scale of production testifies to the value of these locations and for their repeated use for the renewal and replenishment of tools.

Evidence of movement away from these site-specific locations and activity within the broader landscape is often more difficult to identify. Relatively small assemblages of material have been recorded at locations where artefacts with Levallois technology were found in association with faunal remains, such as at Stoke Tunnel, Ipswich, Suffolk (Wymer, 1985), where associated animals included mammoth, horse and red deer. More detailed research on the wider landscape setting of Maastricht-Belvédère (Kolen et al., 1999; Roebroeks et al., 1992) has hinted at potentially complex variations in the use of the European environment by hominin groups. This work has highlighted a wide range of upland and lowland locations, often with variations in tool manufacture, use and discard. It has been suggested (White et al. 2006) that the upland locations provided raw material and opportunities to observe animal movements in the lowland, which in turn were exploited for subsistence activities before return to the upland. It is possible that this model is applicable at Purfleet; White et al. (2006) considered that, despite variations within individual sites, it was highly likely that broad patterns of assemblage composition and location existed in the data from the Thames Valley, from which planned and repeated use of the landscape might be determined. Although they stressed the limited number of sites available to provide evidence for hominin activity in the Early Middle Palaeolithic, they cited Creffield Road, West London as a possible location for renewing materials and tools within the valley. Furthermore they argued that it was highly likely that many of the features apparent in the archaeological record were not isolated but were directly representative of early human behaviour across much of continental Europe. Within this mix, the site at Purfleet represents one of several locations in the Lower Thames valley where the ready availability of flint raw material led to a concentration of hominin activity nearby throughout the interval during which Levallois technology was first used on an industrial scale. That this occurred at the same time, within the resolution of the Quaternary climato-stratigraphical and geochronological framework, as a comparable technological transition in southern France (at Orgnac 3) implies that this was indeed a widespread and synchronous Palaeolithic boundary, one that is of potential significance in the interpretation of assemblages from undated localities.

10. CONCLUSIONS

This paper has reported the combined results of developer-funded geoarchaeological research projects in the vicinity of the Purfleet locality in the Lower Thames, one of a small number of sites at which the MIS 9 interglacial is represented in north-west Europe. An important aim was to test the validity of the reported tripartite Palaeolithic sequence at Purfleet, with successive Clactonian, Acheulian and Levallois industries; however, the stratigraphical resolution over much of the area was less than optimal, precluding testing of the change from Acheulian to Levallois between the Bluelands and Botany gravels. Notwithstanding that, the timing of the appearance of Levallois technique might need to be revised to within MIS 9, rather than at the MIS 9–8 transition, since it would seem that a greater part of the sedimentary sequence at Purfleet can now be attributed to MIS 9, perhaps all of the uppermost fluvial deposits. There is further corroboration of the estuarine character of the laminated silts at Purfleet (Bed 4) and, intriguingly, a strong indication that higher beds within the stratigraphy might represent the return of estuarine conditions, this being linked to the evidence that more of the sequence dates from the MIS interglacial 9. The work has included new geochronology, which provides good support for the MIS 9 attribution, and palaeoclimatic reconstructions from ostracod assemblages and stable isotope analyses of shells and carbonate nodules, which point to warmer-than-present summer temperatures.

ACKNOWLEDGEMENTS

The construction of HS1 was a major project that involved valuable contributions by a vast number of people. The principal phases of fieldwork were undertaken on behalf of Wessex Archaeology by Phil Harding, Mike Dinwiddy, Steve George and Jamie Wright, supported by a field team too many to mention individually, and managed by Andy Crockett. Thanks are also extended to members of Oxford Archaeology who undertook the initial phases of test pitting and diversion of utilities, principal among these are Stuart Foreman (project manager) and Liz Stafford (fieldwork director). Wessex Archaeology particularly wishes to offer thanks to Mark Roberts, external Palaeolithic monitor, and to Peter Allen and David Bridgland for their specialist geological advice and support in the compilation of the field record.

Inevitably the successful completion of the project could not have been achieved without the support of staff from Rail Link Engineering (RLE), especially Helen Glass (Senior Archaeologist), Steve Haynes (finance and programme), Jay Carver, Brigitte Buss and Mark Turner (fieldwork), Avril Randall (borehole librarian) and, from Eurolink, developers of the Purfleet Cutting section. Major contributions were also made by Deborah Priddy, who monitored work on behalf of English Heritage and Pete Murphy (University of East Anglia), English Heritage Science Advisor. Finally thanks are extended to Richard Havis (Essex County Council) for his collaborative support throughout the project.

The post-excavation programme was managed by Andy Crockett, on behalf of Oxford Wessex Archaeology Joint Venture, with all figures and object drawings prepared by Liz James. Specific mention should include thanks to many of the contributors for their permission to allow inclusion of results not undertaken as part of the HS1 construction; this decision, ratified by RLE, made it possible to ensure that the results of work relating to the HS1 could be better placed in regional and international contexts. Further information and illustrative material is available in the various online supplement appendices; there is also a comprehensive project archive (for details contact Wessex Archaeology).

In particular, the opening of sections in Greenlands and Bluelands Quarries, published by Schreve et al. (2002), was funded by the Nature Conservancy Council for England (now part of Natural England), the Geologists’ Association (G.W. Young Fund), the Bill Bishop Memorial Trust and the Quaternary Research Association (Young Persons Research Awards). Other associated commissioning bodies include Bellway Homes (Esso Sports Field), QED Distribution Park (Greenlands West Face), and Chatelain Properties (Armor Road and parts of both Bluelands and Greenlands Quarries). The Armor Road project was coordinated by Essex County Council’s Field Archaeology Unit.

Finally, the authors and Oxford Wessex Archaeology Joint Venture would like to extend their gratitude to Mark Roberts, Jane Sidell and Rachel Ballantyne for providing internal peer review of this report.

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Figure captions

Fig. 1 Location of the various parts of the complex Purfleet site: A – Location within SE England; B – The Purfleet area of the Lower Thames, showing the line of the HS1 and the 1997–1998 Ship Lane locality on the A13; C -Map of the main Purfleet sites and HS1 investigation points. The box indicates the area of Fig. 14. Test pits 3958TP – 3961TP, labelled in grey, were excavated beyond the limit of the Purfleet Pleistocene deposits to investigate the potential for finds on the surface of the Chalk; they revealed infilled solution features modified by cryoturbation features, with no archaeology.

Fig. 2 Map showing the Lower Thames terraces in the Purfleet area, indicating the principal Palaeolithic and interglacial localities and the sinuous abandoned Corbets Tey course, the 'Ockendon Loop'.

Fig. 3 Idealized transverse section through the Lower Thames terraces, showing the stratigraphical position of the Purfleet sediments.

Fig. 4 Recorded section along the HS1 cutting, interpreted to show the main divisions, based on the watching brief. This full section also shows locations of assessment test trenches (which did not coincide exactly with HS1 cutting and were at different orientations). Bed numbers used in the text (and compatible with previous schemes for Purfleet) are indicated. Note that the Bluelands and Botany Gravels cannot be distinguished at any point in this transect. Inset shows locations.

Fig. 5 Detail of Fig. 4, SE of Trench 3954, showing the effects of Chalk solution. Vertical exaggeration is x2 in both parts.

Fig. 6 Sections through the Purfleet deposits transverse to the alignment of the HS1, including detail of Section 108. Inset shows locations. The occurrence of *Bithyinia tentaculata* opercula in basal Sample 114 (noted during investigation for ostracods) showed that this represented Bed 3 and not the Little Thurrock Gravel (Bed 2).

Fig. 7 Section in Trench 3957TT. Much of the lower part of the trench coincided with the infill of a probable prehistoric or later chalk/flint mineshaft (locally termed a 'denehole'), an interpretation confirmed by the recovery of a domesticated cow skull, with traces of butchery using a metal saw (see Appendix II, online supplement). Inset shows location.

Palaeocurrent directions, based on foreset orientation, are shown (amount of dip above direction dip).

Fig. 8 Section in Trench 3982TT. Inset shows location. Palaeocurrent directions shown (as in Fig. 7), ranging from 24°/270° to 20°/205°, although most were oriented towards the west/south-west at approximately 20°/230°.

Fig. 9 Section in Trench 3956TT. Note the ice-wedge cast. Inset shows location. Palaeocurrent directions shown (as in Fig. 7).

Fig. 10 Section in Trench 3955TT. Inset shows location.

Fig. 11 Section in Trench 3954TT. A solution feature affects the upper two steps. Inset shows location. The two monolith samples from the laminated silts were unproductive.

Fig. 12 Section in Trench 3953TT. The area shown in detail has suffered solution-related subsidence. Inset shows location. Sample 5399 yielded ostracods as well as calcareous concretions for analysis (see below); monolith sample 5390 was unproductive).

Fig. 13 McKellar's Section ARC 3962SE. Inset shows locations.

Fig. 14 Section in the northern edge of Greenlands Quarry created during work undertaken prior to the construction of the Armor Road extension. Inset shows locations. In addition to the stratigraphical notation used in this paper and by Schreve et al. (2002), archaeological contexts, defined with respect to internal subdivisions within beds, are shown (indentified by letters).

Fig. 15 Section at the western end of Greenlands Quarry, showing locations of artefacts, faunal remains and samples, including for OSL dating.

Fig. 16 Temporary sections recorded during construction of the A13 dual carriageway road at Ship Lane, Aveley, showing locations of faunal samples. Unfortunately these temporary sections were buried before further recording and sampling could take place, so relative heights have been reconstructed from chainage information and no particle-size analyses of the laminated facies were possible.

Fig. 17 Specimen of the large freshwater mussel *Margaritifera auricularia* exposed in situ in the Shelly Gravel (Bed 3) in the Greenlands Quarry west face section (2001). The fossil was preserved within a large oncoid, which had been broken open during cutting back of the quarry face, revealing the shell.

Fig. 18 SEM images of adult specimens of ostracods recovered from Bed 5 of the Greenlands Quarry north-east section. (A) *Cyprideis torosa*, m, rv, (B) *C. torosa*, f, rv, (C) *Limnocythere inopinata*, f, lv, (D) *L. inopinata*, m, rv, (E) *Scottia tumida*, f, rv, (F) *Cytherissa lacustris*, f, rv, (G) *Darwinula stevensoni*, f, lv, (H) *Ilyocypris salebrosa*, f, rv, (I) *Ilyocypris inermis*, f, lv, (J) *Ilyocypris decipiens*, f, lv, (K) *Ilyocypris lacustris*, f, lv, (L) *Fabaeformiscandona caudata*, f, lv, (M) *Candona neglecta*, f, lv.
Notes: f = female, m = male, lv = left valve, rv = right valve. All specimens in external left lateral view.

Fig. 19 Comparative valve morphology (all female left valves) of *Ilyocypris decipiens* and *Ilyocypris lacustris.* (A–D) *I. decipiens*: (A) external lateral view, (B) dorsal view, LV, (C) internal lateral view, (D) detail of postero-ventral inner lamella showing absence of ripplets (E–H). *I. lacustris* (E) external lateral view, (F) dorsal view, (G) internal lateral view, (H) detail of postero-ventral inner lamella showing five prominent ripplets and three or four additional faint ones.

Fig. 20 Pollen diagram from monolith 101, Section 108 (see Fig. 6)

Percentages have been calculated as follows:

Sum	% total dry land pollen (tdlp)
Marsh & aquatic	% tdlp sum of marsh & aquatics
Spores	% tdlp + sum of spores
Misc.	% tdlp + sum of misc. taxa (*Pediastrum*, Hystrichospheres and pre-Quaternary palynomorphs)

Taxonomy, in general, follows that of Moore and Webb (1978) modified according to Bennett et al. (1994) for pollen types and Stace (1991) for plant descriptions. These procedures were carried out in the Palaeoecology Laboratory of the School of Geography, University of Southampton.

Fig. 21 Clactonian artefacts from Bed 2 (Little Thurrock Gravel) in Greenlands west face (1) and HS1 3954TT (2-4).

Fig. 22 'Proto Levallois' cores from the deformation feature infills (1) and the Bluelands/Botany Gravel (Bed 6/8) at the feather edge of the fluvial deposits (2 and 3).

Fig. 23 'Proto Levallois' cores from the feather edge of the fluvial deposits (Bed 6/8) (1 ns 2), the fill of a denehole (3) and McKellar's Section (4).

Fig. 24 1 and 2: Hand axes from deformation features at the feather edge of the fluvial Bluelands/Botany Gravel (Bed 6/8), 3: from Bluelands/Botany Gravel (Bed 6/8) HS1 3955TT, 4: from involutions below Bed 6/8 HS1 3955TT.

Fig. 25 Carbonate concretions from the HS1 excavation, Purfleet.

Fig. 26 Micrographs showing the internal structure of three of the Purfleet carbonate concretions. In each case a bivalve shell (labelled S) core is surrounded by accumulations of secondary carbonate. The two significant micromorphological characteristics of these concretions are (1) weak internal laminations (L) and (2) zones of orange/brown staining (O/B).

Fig. 27 Oxygen and carbon isotopic composition of carbonate concretions from the Purfleet sequence.

Fig. 28 Comparison of the stable oxygen and carbon isotopic composition of oncoids from Purfleet and from modern contexts.

Fig. 29 Stable isotopic composition of shells from borehole BHC4, Esso Sports ground, Purfleet. Data are plotted against shell isotope data from the modern Thames (Davies et al., 2000) and two other contemporary sites; Greenlands pit (Schreve et al., 2002) and Hackney Downs (Green et al., 2006).

Fig. 30 Plot of the relationship between shell oxygen isotope chemistry and mean summer temperatures in Birtish interglacials. The mean $\delta^{18}O$ value of the shells from the Esso sports ground at Purfleet provide no evidence for temperatures greatly in excess of those of the present day.

Fig. 31 D/L values of Glx for the Free amino acid (FAA; bF; left) and Total Hydrolysable amino acid (THAA; bH*; right) fraction of bleached (intra-crystalline) *Bithynia* opercula from the Purfleet horizons and for the database of MIS 9 and MIS 11 material. The data for other MIS 9 sites (including Purfleet, Cudmore Grove and Grays) and MIS 11 sites (including Swanscombe, Ebbsfleet, Woodston, Clacton, Elveden, Beeches Pit and Hoxne) have also been plotted for comparison. For each site, the base of the box indicates the 25th percentile. Within the box, the solid line plots the median and the dashed line shows the mean. The top of the box indicates the 75th percentile. Where more than 9 data points are available, the 10th and 90th percentiles can be calculated (shown by lines below and above the boxes respectively). The results of each duplicate analysis are included in order to provide a statistically significant sample size. Note different scales on the y-axes.

Fig. 32 Sea-level curve for the past 500 ka, based on data from two sediment cores from the Red Sea (after Siddall et al., 2003). The three warm substages of MIS 9 are separately labelled. Shaded zones signify data gaps.

Table captions:

Table 1 Summary of data sources and analyses undertaken by projects reported in this paper.

Table 2 Clast lithology of the Purfleet deposits, with comparative data from elsewhere in the Lower Thames.

Table 3 Vertebrates from the Purfleet deposits.

Table 4 Molluscs from the Purfleet deposits.

Table 5 Ostracoda and other organic remains from microfossil samples.

Table 6 Mutual Ostracod Temperature Ranges: estimated air temperature ranges (^{o}C) for July and January at MIS9 sites.

Table 7 Pollen counts from Bed 8ii.

Table 8 Summary of archaeological material from Purfleet.

Table 9 Details of the (Proto) Levallois cores from the HS1. 1–6 are the criteria defined by Boëda (1995); see also White and Ashton (2003, Fig. 5).

Table 10 Statistical summary of the stable isotopic data from the Purfleet oncoids.

Table 11 Summary of Purfleet carbonate isotopic data, compared with that from a modern carbonate system (River Gipping, Suffolk).

Table 12 Raw isotopic data from Purfleet shell samples (ESSO Sports Field site).

Table 13 Summary of OSL dating from the Greenlands Quarry west face (see Fig. 15).

Table 14 Table of p-values from the results of the statistical 2-tailed t-tests performed on amino acid data from from Clacton and Purfleet.

Online supplement: (appendices):

Appendix I – The HS1 project: details of specification, project description and rationale and work undertaken.

Appendix II – Detailed descriptions of the HS1 project exposures and sediment analyses.

Appendix III – Details of methodology in the preparation of samples for various analyses.

Appendix IV – Full report on vertebrate analyses (Danielle Schreve).

Appendix V – Full report on the Palaeolithic archaeology including detailed description of Neolithic material (Phil Harding).

Appendix VI – Full report on the amino acid racemization analysis (Kirsty Penkman).

Table 1

Table 1 Summary of data sources and analyses undertaken by projects reported in this paper

Project / location	Sediment analyses[1]	Vertebrates	Molluscs	Ostracods	Pollen	Artefacts	Stable isotope analysis	OSL dating	Amino acid dating
HS1									
Evaluation sections and test pits (Oxford Archaeology)		✓		✓	✓	✓			✓
Evaluation test trenches (Wessex Archaeology)	✓	✓		✓	✓	✓			✓
Watching Brief		✓				✓			
Non-HS1									
Armour Road	✓	✓	✓			✓			
Greenlands West Face	✓	✓				✓		✓	
Greenlands North Face[2]	✓			✓			✓		
Ship Lane	✓	✓	✓						
Esso Sports Field		✓					✓		

Notes:
[1] - Clast and particle-size analyses
[2] - Greenlands Pit Conservation Section

Table 2

CLASTS: 16-32mm (*11.2-16 in italics*)			FLINT			CHALK	SOUTHERN		EXOTICS						
GRAVEL	**SITE**	SAMPLE	TERTIARY	NODULAR	TOTAL	CHALK*	GREENSAND CHERT	TOTAL	QUARTZ	QUARTZITE	CARB. CHERT	*RHAXELLA* CHERT	IGNEOUS	TOTAL	TOTAL COUNT
East Tilbury Marshes Gravel	East Tilbury Marshes	1 D	58.9	9.9	96.2		0.9	1.1	0.9	0.7	0.5	0.3	0.3	2.7	745
	11.2–16	*1 D*	*49.5*	*6.6*	*92.2*		*1.5*	*1.6*	*3.2*	*1.4*	*0.6*	*0.2*	*0.1*	*6.1*	*979*
Mucking Gravel	Lion Pit upper gravel	1 D	67.1	5.9	95.3		0.8	0.8		3.5				3.9	255
	11.2–16	*1 D*	*59.4*	*3.2*	*94.4*		*1.1*	*1.1*	*1.9*	*1.5*	*0.4*	*0.4*		*4.7*	*465*
	Lion Pit lower gravel	1 D	47.8	35.9	97.5	(1.1)	0.7	0.7	0.7	1.1				1.8	276
	(Levallois 'floor') 11.2-16	*1 D*	*50.2*	*19.6*	*95.7*	*(0.3)*	*0.6*	*0.6*	*1.8*	*0.9*	*0.6*		*0.3*	*3.7*	*327*
	Mucking	1A D	64	9.3	97.0		1.1	1.1	0.9	0.6		0.1		1.8	708
	11.2–16	*1A D*	*57.7*	*4.9*	*92.1*		*1.9*	*1.9*	*3.1*	*1.2*	*1.1*	*0.2*	*0.1*	*6.0*	*901*
		1B D	37.4	13.3	92.5		4.9	4.9	1.2	0.6	0.6	0.3		2.6	345
Corbets Tey Gravel	Stifford	1A	51.6	8.4	94.0		0.4	0.4	2.9	1.2	0.6	0.1	0.4	5.5	730
		1B	52.5	NR	92.9		0.9	1.0	3.5	1.4	0.5	0.1		5.9	918
	11.2–16	*1B*	*39.2*	*8.3*	*88.3*		*1.1*	*1.4*	*6.0*	*2.6*	*1.1*	*0.2*	*0.1*	*10.3*	*1277*
Previous Purfleet samples (Bridgland, 1994; Schreve et al., 2002)															
	Esso Pit, Bed 6/8	1A	44.8	16.9	91.8		0.5	0.5	2.5	3.0	1.6			7.4	366
	11.2–16	*1A*	*36.3*	*7.6*	*86.6*		*1.0*	*1.1*	*3.9*	*3.7*	*3.1*	*0.5*	*0.2*	*11.7*	*618*
	Bed 6/8	1B	47.7	18.1	95.0	(37.3)	1.5	1.5	0.8	1.5	0.8	0.4		3.5	260
	Bluelands, Bed 6/8?	2.1	22.8	21.8	90.2		3.2	3.2	1.9	3.2	1.3			6.7	316
	11.2–16	*2.1*	*19.2*	*9.6*	*87.2*		*4.2*	*4.6*	*3.2*	*3.2*	*1.3*	*0.3*		*8.2*	*625*
	Bed 6	3.1	45.6	13.4	92.6		0.8	1.1	1.6	3.3	0.8			6.3	366
	11.2–16	*3.1*	*32.6*	*6.5*	*88.1*		*1.7*	*1.8*	*2.8*	*5.0*	*1.2*	*0.2*	*0.2*	*9.9*	*604**
	Bed 6	3.2	37.3	14.4	92.3		1.7	1.7	1.0	3.5	1.0			5.5	402
	11.2–16	*3.2*	*34.3*	*6.7*	*90.7*		*2.1*	*2.1*	*2.2*	*2.7*	*1.1*	*0.2*		*7.0*	*817**
	Greenlands, Bed 3	1	35.9	22.1	92.8	(17.0)	1.1	1.1	0.4	4.7	0.7	0.3		6.2	276*
	Bed 6 (chalky facies)	2	58.6	9.0	93.7	(91.9)	0.9	1.8	0.9	1.8	1.8			4.5	111*
	11.2–16	*2*	*48.1*	*6.2*	*93.2*	*(149.4)*	*0.6*	*0.6*	*1.2*	*2.5*			*0.6*	*6.2*	*162**
	Bed 6	3	48.8	22.9	93.2	(0.7)	0.7	0.7	1.0	3.1	1.0			5.8	293*
	Bed 6	4	30.4	14.7	93.6		2.6	2.6	1.0	2.9				3.8	312
	Bed 8	5	32.3	18.6	92.4		0.7	0.7	2.1	3.4	0.7		0.3	6.9	291

HS1 (CTRL) Sections:

HS1 3953TT	**Context 5308 – Bed 2**	**5391**	**38.7**	**20.2**	**94.3**	**(5.3)**	**1.8**	**1.9**	**0.6**	**2.3**	**0.2**	**0.2**		**3.4**	**618***
HS1 3954TT	**Context 5408 – Bed 2**	**5492**	**29.2**	**22.2**	**92.1**		**1.5**	**1.7**	**1.3**	**2.6**		**0.6**		**4.5**	**531***
	11.2-16	***5492***	***23.2***	***11.2***	***88.9***		***3.6***	***4.1***	***1.6***	***4.3***	***0.6***	***0.1***	***0.1***	***7.0***	***859****
	Context 5405 – Bed 6/8	**5495**	**37.9**	**13.8**	**92.5**		**1.9**	**1.9**	**1.0**	**3.0**	**0.9**	**0.3**		**5.2**	**572**
HS1 3955TT	**Context 5506 – Bed 6/8**	**5590**	**47.8**	**11.4**	**94.5**		**0.5**	**0.5**	**0.8**	**3.9**	**0.1**		**0.1**	**5.0**	**763**
	Context 5505 – Bed 6/8	**5591**	**50.7**	**11.8**	**93.0**		**0.8**	**0.9**	**1.0**	**3.9**	**0.8**		**0.2**	**5.9**	**977**
HS1 3956TT	**Context 5610 – Bed 6/8**	**5693**	**60.3**	**6.6**	**94.7**		**0.3**	**0.3**	**1.0**	**3.4**	**0.2**	**0.1**	**0.1**	**4.9**	**911***
	Context 5614 – Bed 6/8	**5694**	**60.6**	**11.5**	**93.4**		**0.8**	**1.1**	**1.7**	**3.3**	**0.1**		**0.1**	**5.4**	**976**
HS1 3957TT	**Context 5707 – Bed 8iii**	**5790**	**43.8**	**17.8**	**95.9**			**0.6**		**1.9**	**0.3**		**0.6**	**2.8**	**320***
	Context 5704 – Bed 6/8	**5793**	**48.6**	**24.5**	**95.2**		**0.9**	**0.9**	**1.8**	**1.8**		**0.3**		**3.9**	**331***
HS1 3982TT	**Context 8221 – Bed 6/8**	**8293**	**43.2**	**21.9**	**95.0**		**0.6**	**0.6**	**0.8**	**2.7**	**0.4**			**4.3**	**516***
	Context 8234 – Bed 8iii	**8294**	**30.4**	**19.6**	**92.4**		**3.3**	**3.3**		**2.2**		**2.2**		**4.3**	**92***
	11.2–16	***8294***	***33.4***	***8.5***	***91.5***		***5.1***	***5.5***	***0.2***	***0.8***	***0.8***	***0.6***		***2.8***	***505****
	Context 8210 – Bed 8iii	**8295**	**52.3**	**13.7**	**97.1**		**1.1**	**1.1**	**0.4**	**1.4**				**1.8**	**277***
	11.2–16	***8295***	***66.1***	***5.2***	***95.6***		***1.8***	***1.9***	***0.3***	***1.1***	***0.3***	***0.2***	***0.2***	***2.2***	***1003****

Armor Road Extension Project:

Armor Road	**Botany Gravel – Bed 8**	**D**[1]	**24.7**	**23.0**	**94.6**		**0.3**	**0.7**	**1.7**	**2.7**		**0.3**		**4.7**	**296**
Greenlands north face[2]	**Bluelands Gr. – Bed 6**	**6**[2]	**51.6**	**11.1**	**93.9**		**0.5**	**0.5**	**1.2**	**3.4**	**0.7**			**5.6**	**585***
Greenlands north face[2]	**Shelly gravel – Bed 3**	**7**[2]	**44.3**	**14.4**	**92.6**	**(12.6)**	**1.5**	**1.5**	**1.1**	**4.4**		**0.4**		**5.9**	**271***
	11.2-16	**7**[2]	***33.9***	***8.9***	***91.5***	***(17.9)***	***1.3***	***1.3***	***0.9***	***4.9***	***0.4***	***0.4***		***7.1***	***224****
Armor Road	**L.Thurr. Gr – Bed 2**	**O(iv)**[3]	**32.8**	**19.2**	**93.9**	**(1.0)**	**0.9**	**1.1**	**1.1**	**3.0**	**0.5**	**0.1**	**0.1**	**5.0**	**965***
Greenlands north face[2]	**L.Thurr. Gr – Bed 2**	**8**[2]	**41.0**	**16.1**	**95.9**	**(10.5)**	**1.3**	**1.3**		**1.6**	**0.3**		**1.0**	**2.9**	**315***

Greenlands West Face Project:

Greenlands	**Bed 2**	**G1**	**30.9**	**26.4**	**94.3**	**(6.5)**	**2.0**	**2.2**	**0.7**	**2.6**				**3.3**	**459***
	11.2–16	***G1***	***22.2***	***7.9***	***88.4***	***(8.3)***	***3.0***	***3.5***	***2.0***	***4.2***	***0.9***	***0.1***	***0.3***	***8.1***	***953****
	Bed 2	**G2**	**33.2**	**23.8**	**95.2**	**(0.2)**	**0.7**	**0.7**	**1.0**	**1.8**	**0.7**			**4.1**	**605***
	11.2–16	***G2***	***25.1***	***10.4***	***90.0***		***2.0***	***2.2***	***2.8***	***3.0***	***0.9***		***0.7***	***7.8***	***867****
	Bed 3	**G3**	**27.8**	**26.6**	**96.8**	**(227.8)**				**1.3**	**1.3**	**0.6**		**3.2**	**158***
	Bed 6/8	**G4**	**45.6**	**11.4**	**94.1**		**0.7**	**0.9**		**3.1**	**1.1**	**0.2**	**0.7**	**5.0**	**456***
	11.2–16	***G4***	***41.4***	***4.4***	***90.0***		***1.7***	***2.2***	***2.0***	***3.1***	***1.1***	***0.3***		***6.9***	***642****
	Bed 6/8	**G5**	**49.8**	**13.2**	**94.7**		**0.7**	**0.7**	**1.7**	**1.5**	**0.7**		**0.2**	**4.5**	**418**
	11.2–16	***G5***	***35.7***	***7.7***	***89.2***		***1.4***	***1.4***	***1.9***	***5.0***	***1.4***	***0.1***	***0.1***	***9.2***	***697****
	Bed 6/8	**G6**	**37.4**	**13.1**	**92.1**		**1.0**	**1.7**	**1.0**	**3.2**	**1.5**			**6.2**	**406***
	11.2–16	***G6***	***40.7***	***4.4***	***88.7***		***1.0***	***1.4***	***2.0***	***5.5***	***0.9***		***0.2***	***9.9***	***868****

A13 Project, Ship Lane Bridge:

Ship Lane	**Ship Lane bridge abut.**	**1**	**55.0**	**12.1**	**93.3**		**0.6**	**1.0**	**1.6**	**2.2**	**1.0**	**0.3**		**5.8**	**313***
	W of Ship Lane	**2[4]**	**53.9**	**9.8**	**92.4**		**0.6**	**0.6**	**0.9**	**3.8**	**1.2**	**0.3**		**6.6**	**317***
	W of Ship Lane	**3[4]**	**46.0**	**11.2**	**93.1**		**0.7**	**1.4**	**0.4**	**3.9**	**1.1**			**5.4**	**276***
	E of Ship Lane	**4[5]**	**53.6**	**12.5**	**91.5**		**0.9**	**0.9**	**1.6**	**3.7**	**1.3**			**7.2**	**319***
	E of Ship Lane	**5[5]**	**56.9**	**10.9**	**94.8**			**0.2**	**1.2**	**2.8**	**0.4**			**4.4**	**248***
	Globe Pit	1 D	57.9	11.2	93.1		3.2	3.5	0.8	1.1	1.1	0.2		3.4	653
	Globe Pit	2 D	50.2	10.5	93.2		3.1	3.1	1.3	0.7	0.7	0.8		3.7	617
	11.2–16	*2 D*	*40.7*	*5.4*	*90.5*		*4.4*	*4.7*	*2.1*	*0.8*	*1.2*	*0.2*	*0.1*	*4.5*	*1453*
	Globe Pit	3 D	64.6	8.9	94.4		2.4	2.4	1.5	1.0	0.4			3.2	463
	Barvills Farm Pit	1 D	67.9	11.8	92.9		3.3	3.3	1.7	1.1	0.4	0.1		3.6	722
	11.2–16	*1 D*	*55.6*	*5.6*	*91.8*		*2.7*	*2.9*	*2.2*	*1.1*	*1.1*	*0.3*	*0.3*	*5.3*	*1138*
Orsett Heath Gravel	Hornchurch railway cutting	1	41.8	0.7	92.6		2.3	2.3	2.0	1.4	0.6	0.6		5.1	352
		2	28.9	11.7	90.2		1.6	1.9	1.9	2.3	1.6	0.9	0.9	7.9	429
	Hornchurch Dell	1	54.0	7.7	91.7		1.5	1.5	2.1	2.8	1.2	0.4		6.7	676
	Globe Pit North	1A D	41.4	9.0	90.4		4.1	4.4	0.6	1.4	1.6	0.3		5.2	365
	Linford	1 D	64.6	11.6	96.0		2.2	2.4	0.7		0.2		0.2	1.7	424
	Linford	2 D	84.2	4.0	95.7		1.4	1.6		0.5		0.2	1.2	2.7	625
	11.2–16	2 *D*	*28.0*	*3.6*	*91.3*		*1.1*	*1.2*	*3.9*	*2.3*	*0.6*	*0.2*	*0.5*	*7.4*	*665*
Swanscombe Lower Middle Gravel	Barnfield Pit	1 D	58.2	9.8	93.9		0.9	1.2	2.4	1.8	0.5			4.8	1081
	11.2–16	*1 D*	*50.9*	*5.3*	*89.9*		*2.1*	*2.3*	*4.4*	*2.0*	*0.8*		*0.1*	*7.7*	*1703*
	Barnfield Pit	2 D	48.5	12.7	92.7		1.9	2.0	1.9	1.8	0.5	0.1	0.2	5.0	992
	11.2–16	*2 D*	*41.6*	*5.5*	*89.7*		*3.0*	*3.1*	*3.5*	*1.5*	*0.5*	*0.2*	*0.2*	*6.8*	*1785*
Swanscombe Lower Gravel	Barnfield Pit	3 D	55.5	8.3	94.3		1.0	1.0	2.3	1.3	0.5	0.2	0.1	4.5	931
	11.2–16	*3 D*	*36.5*	*5.9*	*89.0*	*(0.1)*	*2.5*	*2.7*	*4.0*	*2.9*	*0.5*	*0.1*	*0.1*	*8.3*	*1391*
	Barnfield Pit	4 D	30.5	11.8	94.1	(0.4)	2.7	2.8	1.1	0.8	0.4	0.1		2.7	857
	11.2–16	*4 D*	*28.1*	*8.8*	*90.6*	*(0.3)*	*3.5*	*3.8*	*2.7*	*1.5*	*0.9*	*0.2*		*5.6**	*1494*

Notes: D denotes downstream of the Darent confluence; * denotes the presence of non-durables not included in total. Chalk shown as percentage of total durables. Other non-durables include pyrite and cement-stone from the London Clay, clay clasts and other argillaceous and/or calcareous material, including fossils

1 – From the Armor Road excavation, Fig. 13, Context D; not published previously

2 – These data, published previously by Schreve et al. (2002) come from the area of the Armor Road extension but were collected from the north face of Greenlands quarry before the Armor Road project commenced. The earlier publication should be consulted for further details.

3 – This sample was from the Armor Road section (see Fig. 13), its number synonymous with the THAR 1998 context number.

4 – Sample from west of Ship Lane (Fig. 15, inset); lower gravel

5 – Sample from east of Ship Lane (Fig. 15, inset); lower gravel

Table 3

Table 3: Vertebrates from the Purfleet deposits

	Bed 3						3-5	Bed 4			Bed 5			6	6/8	
	ARC 361 00	3953TT	ARC 310 T02	Armor Road	Greenlands west face	Schreve et al., 2002	Stonehouse Lane*	ARC 361 00	Greenlands west face	Esso Sports Ground**	Armor Road	Greenlands west face	Schreve et al., 2002	Armor Road	Botany Pit***	Ship Lane****
PISCES																
Acipenser sturio													x			
Anguilla anguilla	x						x	x		x		x	x			
Salmo sp.							x									
Esox lucius	x	x			x	x	x	x	x	x		x	x			
Gasterosteus aculeatus							x	x		x			x			
Abramis bjoernka													x			
Abramis brama							x									
Leuciscus leuciscus													x			
Leuciscus sp.							x									
Rutilus rutilus	x	x					x	x					x			
Tinca tinca							x			x			x			
Scardinius erythropthalmus	x	x					x	x					x			
Cyprinidae spp	x	x			x	x		x	x	x		x				
Perca fluviatilis							x						x			
Pisces, indet.	x	x			x			x	x		x	x	x			
AMPHIBIA																
Triturus cf. *cristatus*													x			
Triturus sp.													x			
Bufo bufo													x			
Bufo sp.													x			
Rana dalmatina													x			
Rana cf. *lessonae*													x			
Rana arvalis													x			
Rana cf. *temporaria*													x			
Anura sp.	x							x	x			x	x			

	Bed 3						3-5	Bed 4			Bed 5			6	6/8	
	ARC 361 00	**3953TT**	**ARC 310 T02**	**Armor Road**	**Greenlands west face**	**Schreve et al., 2002**	**Stonehouse Lane***	**ARC 361 00**	**Greenlands west face**	**Esso Sports Ground****	**Armor Road**	**Greenlands west face**	**Schreve et al., 2002**	**Armor Road**	**Botany Pit*****	**Ship Lane******
REPTILIA																
Emys orbicularis									x							
Anguis fragilis													x			
Natrix natrix													x			
Ophidia sp.								x					x			
AVES																
Branta or *Anser*											x					
Passeriformes sp.											x					
Aves spp., indet.											x		x			
MAMMALIA																
Myotis bechsteinii							x									
Sorex araneus													x			
Sorex minutus							x						x			
Sorex sp.							x				x					
Neomys sp.							x						x			
Crocidura leucodon							x									
Crocidura sp.													x			
Soricidae sp.													x			
Macaca sylvanus													x			
Castor fiber													x			
Clethrionomys cf. *glareolus*		x					x						x			
Clethrionomys sp.	x															x
Arvicola terrestris cantiana							x	x					x			
Microtus agrestis	x						x						x			
Microtus arvalis													x			
Microtus sp.	x	x				x		x	x				x			x

	Bed 3						3-5	Bed 4			Bed 5			6	6/8	
	ARC 361 00	**3953TT**	**ARC 310 T02**	**Armor Road**	**Greenlands west face**	**Schreve et al., 2002**	**Stonehouse Lane***	**ARC 361 00**	**Greenlands west face**	**Esso Sports Ground****	**Armor Road**	**Greenlands west face**	**Schreve et al., 2002**	**Armor Road**	**Botany Pit*****	**Ship Lane******
Apodemus sylvaticus	x	x					x	x				x	x			x
Mustela sp.									x							
Crocuta crocuta													x			
Felis cf. *silvestris*													x			
Palaeoloxodon antiquus													x			
Elephantidae sp.													x		x	
Equus ferus							x							x	x	
Dama dama				x	x								x			
Cervus elaphus			x	x									x		x	
Capreolus capreolus													x			
Cervidae, indet.				x	x								x			
Bos primigenius															x	
Bovidae, indet.			x										x			
Mammalia, indet.	x	x		x	x			x	x		x	x		x		x

Notes:
* - The Stonehouse Lane assemblage (from Bridgland et al., 1995), is from a disturbed and undifferentiated feather-edge of the sequence, probably incorporating Beds 3–5
** - Finds from two productive levels, IC 6.55–6.7and 4C 7.95–8.4 m OD
*** - The Botany Pit material was found by A.J.Snelling (Roe, 1981 and pers. comm.. to P. Allen) and was identified by B. Westley, Institute of Archaeology, in 1963
**** - No attempt has been made to allocate the Ship Lane sediments to the beds defined at Purfleet.

Table 4

Table 4 Molluscs from the Purfleet deposits: new analyses from Armor Road and Ship Lane

	Armor Road	Ship Lane, Aveley – A 13 road cutting							
	Bed 5	M1	M2	M3	A	B	C	D	E
Aquatic taxa									
Valvata cristata Müller			5	-	1	6	3	-	-
Valvata piscinalis (Müller)	80		25	5	12	24	18	-	1
Bithynia tentaculata (Linnaeus)	121		26	13	16	52	25	-	2
Bithynia opercula	[456]				[36]	[60]	[92]	[205]	[19]
Belgrandia marginata (Michaud)	306	-	-	-	-	-	1	-	-
Galba truncatula (Müller)			1	9	6	2	2	-	-
Radix balthica (Müller)			7	-	4	3	6	-	-
Lymnaeidae indet.	11				-	-	3	1	-
Planorbis planorbis (Linnaeus)			1	-	-	-	1	-	-
Anisus leucostoma (Millet)			5	1	-	-	5	-	-
Anisus vorticulus (Troschel)			*	-	1	-	-	-	-
Anisus spp.	1				4	2	-	-	3
Gyraulus laevis (Alder)			3	-	-	1	3	-	-
Gyraulus albus (Müller)			6	1	6	-	2	-	-
Gyraulus crista (Linnaeus)	1		6	3	3	2	1	-	-
Planorbidae indet.				1	6	3	10	6	-
Hippeutis complanatus (Linnaeus)	1								
Ancylus fluviatilis (Müller)	17		-	-	-	-	-	1	-
Acroloxus lacustris (Linnaeus)	78		-	1	-	-	-	-	-
Unio pictorum (Linnaeus)									
Unio spp.	32				-	-	-	-	-
Anodonta spp.	1								
Corbicula fluminalis (Müller)	147		-	-	-	1	-	8	14
Sphaerium corneum (Linnaeus)	2		-	-	1	-	-	-	-
Pisidium amnicum (Müller)	2		-	1	2	-	1	-	-
Pisidium clessini Neumayr	1		-	-	-	-	-	1	-
Pisidium casertanum (Poli)			-	1	-	1	-	-	-
Pisidium subtruncatum Malm			-	-	1	-	-	-	-
Pisidium supinum Schmidt	10		-	-	-	-	-	3	1
Pisidium henslowanum (Sheppard)	90	2	2	28	5	3	12	18	142
Pisidium nitidum Jenyns	7	2	1	11	3	1	-	-	-
Pisidium moitessierianum Paladilhe	303	-	1	2	1	-	15	24	8-
Pisidium tenuilineatum Stelfox	12	-	-	-	1	-	-	1	-
Pisidium spp.	4				1	5	22	2	-
Terrestrial taxa									
Carychium minimum Müller		6			3	2			
Carychium tridentatum (Risso)		2							
Carychium spp.		10	9		2	3			
Succineidae indet.	1	8	3	5	15	9			
Azeca goodalli (Férussac)						1			
Cochlicopa lubrica (Müller)		6				9			
Cochlicopa lubricella (Porro)						4			
Cochlicopa nitens (Gallenstein)		1				1			
Cochlicopa spp	1	63	7		61	19			
Truncatellina cylindrica (Férussac)		7			1	3			

Table 4 Molluscs from the Purfleet deposits: new analyses from Armor Road and Ship Lane

Truncatellina sp.					3	1		
Vertigo pusilla Müller		4			1	4		
Vertigo antivertigo (Draparnaud)		8	1		6	12		
Vertigo moulinsiana (Dupuy)						1		
Vertigo angustior Jeffreys		1			3			
Vertigo spp.		3	1		14	2		
Pupilla muscorum (Linnaeus)		89	2	1	52	19		
Vallonia costata (Müller)		85	2	1	28	27		
Vallonia pulchella (Müller)		278	95	16	172	322		
Vallonia enniensis (Gredler)		8		1	4	27		
Vallonia excentrica Sterki		5						
Vallonia spp.		411	178	28	446	236		
Acanthinula aculeata (Müller)		19			10	1		
Punctum pvgmaeum (Draparnaud)		76	8		54	50		
Discus ruderatus (Férussac)		1			1	1		
Discus spp.	1		1		1			
Vitrina pellucida (Müller)		4				12		
Vitrinidae indet.		13	2		10			
Vitrea crystallina (Müller)		4			1	3		
Vitrea contracta (Westerlund)	1				1	1		
Vitrea spp.		7			7	10		
Nesovitrea hammonis (Ström)		13		1	15	24		
Aegopinella pura (Alder)		4				4		
Aegopinella spp.					7			
Zonitoides nitidus (Müller)						3		
Zonitidae indet.		4	1	1	1	1		
Milax spp.		23	2		23	1		
Limax spp.	1	7	35	12	65	9	1	1
Euconulus fulvus (Müller) agg.		4			1	3		
Macrogastra spp.						1		
Clausilia pumila Pfeiffer		1						
Clausiliidae indet.	1	1			2	1		
Candidula crayfordensis Jackson						5		
Cernuella virgata (da Costa)		14						
Trochulus hispidus (Linnaeus)	2	80			66	19		
Cepaea nemoralis (Linnaeus)						11		
Cepaea spp.		62			28	39		
Cepaea/Arianta indet.	1							

Ship Lane ‘spot’ samples:
A: Sandy silt. Thames Bank
B: Shelly silt. North edge, north carriageway
C: Shell bed. South carriageway bridge, south side
D: South carriageway above thin gravel over chalk
E: Sand with comminuted shell 27/4/98

Table 5

Table 4 Ostracoda and other organic remains from microfossil samples

	UNIT NO.	CONTEXT	SAMPLE NO.	DEPTH IN SECTION (m)	*Candona angulata* G. W. Müller, 1900	*Candona neglecta* Sars, 1887	*Candona* sp. (juveniles & fragments)	*Cyprideis torosa* (Jones, 1850)	*Cypridopsis vidua* (O. F. Müller, 1776)	*Cytherissa lacustris* (Sars, 1863)	*Darwinula stevensoni* (Brady & Roberston, 1870)	*Fabaeformiscandona caudata* (Kaufmann, 1900)	*Herpetocypris* sp.	*Ilyocypris decipiens Masi, 1905*	*Ilyocypris inermis* Kaufmann, 1900	*Ilyocypris lacustris* Kaufmann, 1900	*Ilyocypris salebrosa* Stepanaitys, 1959	*Ilyocypris* sp. (unidentified adults & juveniles)	*Limnocythere inopinata* (Baird, 1843) (both sexes)	*Pseudocandona* sp. (juveniles)	*Scottia tumida* (Jones, 1850)	unidentified cypridoideans (fragments)	Brackish ostracods	Freshwater ostracods	Tubes (rootlets and stems)	*Bithynia* (opercula)	Molluscs	Charophyte oogonia	Fish teeth & bone	Small mammal teeth
SECTION 108 STARLAND	BED 4	117	103	1.81-1.91			x	x			x			x			x						x	x	x					
			104	1.91-2.01			x	x			x			x	x				x				x	x	x	x				
			105	2.01-2.11			x	x			x			x	x				x				x	x	x	x				
			106	2.11-2.21			x	x			x			x	x				x				x	x	x					
			107	2.21-2.31				x			x			x	x				x	x			x	x	x	x				
			108	2.31-2.47			x	x			x			x					x				x	x	x	x				
	BED 3		109	2.47-2.52				x															x		x	x	x	x	x	x
		119	110	2.52-2.66			x	x						x									x	x	x	x	x	x	x	x
		120	111	2.66-2.71				x															x		x	x	x	x	x	
		121	112	2.71-2.76				x															x			X		x	x	
		122	113	2.76-2.85																						X		x	x	
		123	114	2.85-2.90																						X				
SECTION 108 STARLAND	monolith	117	A	6.25-6.31			x	x			x							x	x				x	x						
	101		B	6.50-6.53			x	x						x									x	x						
	monolith 102	119		5.93-5.99				x			x												x	x						
3953TT SHELLY BEDS	BED 3		**5399**		x			x	x					x		x	x		x		x		x	x	x	X	x	x	x	x

Table 4 Ostracoda and other organic remains from microfossil samples

	UNIT NO.	CONTEXT	SAMPLE NO.	DEPTH IN SECTION (m)	*Candona angulata* G. W. Müller, 1900	*Candona neglecta* Sars, 1887	*Candona* sp. (juveniles & fragments)	*Cyprideis torosa* (Jones, 1850)	*Cypridopsis vidua* (O. F. Müller, 1776)	*Cytherissa lacustris* (Sars, 1863)	*Darwinula stevensoni* (Brady & Roberston, 1870)	*Fabaeformiscandona caudata* (Kaufmann, 1900)	*Herpetocypris* sp.	*Ilyocypris decipiens Masi, 1905*	*Ilyocypris inermis* Kaufmann, 1900	*Ilyocypris lacustris* Kaufmann, 1900	*Ilyocypris salebrosa* Stepanaitys, 1959	*Ilyocypris* sp. (unidentified adults & juveniles)	*Limnocythere inopinata* (Baird, 1843) (both sexes)	*Pseudocandona* sp. (juveniles)	*Scottia tumida* (Jones, 1850)	unidentified cypridoideans (fragments)		Brackish ostracods	Freshwater ostracods
ESSO GARAGE SITE	Column 180		A	7.47-7.51																		x			x
ESSO GARAGE SITE	Column 180		B	7.34-7.35																					
ESSO GARAGE SITE	Column 180		C	7.13-7.17																					
ESSO GARAGE SITE	Column 178		A	7.08-7.12																					
ESSO GARAGE SITE	Column 178		B	6.90-6.94																		x			x
ESSO GARAGE SITE	Column 178		C	6.72-6.76																		x			x
ESSO GARAGE SITE	Column 179		A	6.64-6.66																					
ESSO GARAGE SITE	Column 179		B	6.57-6.59			x				x							x							x
ESSO GARAGE SITE	Column 179		C	6.49-6.51																					
ESSO GARAGE SITE	Column 179		D	6.43-6.45																					
GREENLANDS QUARRY	BED 5 (Shell Bed)		6	top		x	x	x		x	x	x		x		x		x	x	x	x			x	x
GREENLANDS QUARRY	BED 5 (Shell Bed)		5	middle		x	x	x			x	x	x	x	x	x		x	x	x	x			x	x
GREENLANDS QUARRY	BED 5 (Shell Bed)		4	bottom		x	x	x		x	x	x		x		x	x	x	x		x			x	x
GREENLANDS QUARRY	BED 4 (shell band)		2			x	x	x			x	x		x		x	x	x	x		x			x	x

Table 6

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Table 7

Table 7 Pollen counts from Bed 8ii

	2001 TP	3957 TT
Trees & shrubs		
Betula	33	5
Fagus	2	
Pinus	1	4
Picea		1
Quercus	31	16
Tilia	1	2
Fraxinus	1	
Alnus		52
Corylus avellana	12	22
Rosaceae	1	
Herbs		
Caryophyllaceae		1
Chenopodiaceae		1
Centaurea nigra type		1
Plantago lanceolata type	1	1
Poaceae	16	19
Cyperaceae		6
Aquatics		
Myriophyllum alternifolium	1	
Spores		
Dryopteris type		14
cf. *Pteridium aquilinum*	3	
Pteridium		1
Polypodium		4
Unidentified/degraded	5	9
MISCELLANEOUS		
Pediastrum		3
Pre-Quaternary		5
TOTAL	108	167

Table 8

Table 8: Summary of archaeological material from Purfleet

Site	Geology	Trench	Bed number	Flake core	Core frags	Blades	Broken blades	Blades (total)	Flakes	Broken flakes	Flakes (total)	Chips	Scrapers	Projectile points	Handaxes	Debitage	Misc. retouch	Overall Total	Reference
ARC 2001TP	Late prehistoric	2001	10	1		1		**1**	9	8	**17**							**19**	URL 1995
ARC 2002TP	Late prehistoric	2002	10	1		3		**3**	14	4	**18**							**22**	URL 1995
ARC 2003TP	Late prehistoric	2003	10	2					6	2	**8**						1	**11**	URL 1995
ARC 2004TP	Late prehistoric	2004	10			1	2	**3**	5	5	**10**		1					**14**	URL 1995
ARC PFC01	Late prehistoric	3957TT	10						5	2	**7**			1				**8**	
ARC PFC01	Late prehistoric	3961TP	10			1		**1**	6		**6**	8						**15**	
ARC 310T02	Late prehistoric	310T02	10	8	1	13	18	**31**	120	86	**206**	2	1	2			2	**253**	
Armor Road	Unstratified		9						1		**1**							**1**	
ARC PFC01	Unstratified	3953TT	9						1		**1**							**1**	
ARC PFC01	Unstratified	3955TT	9						1		**1**							**1**	
ARC PFC01	Unstratified	3956TT	9						2		**2**							**2**	
ARC PFC01	Unstratified (denehole)	3957TT	9	1					2		**2**							**3**	
ARC PFC01	Unstratified	3982TT	9							1	**1**							**1**	
ARC 310T02	Unstratified	310T02	9						5	2	**7**				1			**8**	
Greenlands and Bluelands	Unstratified		9						19		**19**							**19**	Schreve *et al* 2002
Greenlands West Face	Unstratified		9						6	6	**12**							**12**	
		Subtotals	***10 to 9***	***13***	***1***	***19***	***20***	***39***	***202***	***116***	***318***	***10***	***2***	***3***	***1***	***0***	***3***	***390***	
ARC 2001TP		2001	8iii						5	4	**9**							**9**	URL 1995
ARC 2002TP		2002	8iii							1	**1**							**1**	URL 1995
ARC PFC01		3957TT	8iii						7	9	**16**							**16**	
ARC PFC01		3982TT	8iii			1		**1**	3	3	**6**							**7**	
ARC 2001TP		2001	8ii							1	**1**							**1**	URL 1995

Site	Geology	Trench	Bed number	Flake core	Core frags	Blades	Broken blades	Blades (total)	Flakes	Broken flakes	Flakes (total)	Chips	Scrapers	Projectile points	Handaxes	Debitage	Misc. retouch	Overall Total	Reference
ARC PFC01		3982TT	8i						4		**4**							**4**	
Armor Road column	Botany		8						2		**2**							**2**	
Armor Road area	Botany		8				3	**3**	25	18	**43**							**46**	
Bluelands Pit	Botany		8			1		**1**	8		**8**				1			**10**	Schreve et al 2002
Bluelands Pit	Botany	3	8	1					12		**12**	1	3				2	**19**	Palmer 1975
ARC 2004TP	Fill of chalk involutions	2004			2				30	11	**41**				3	1		**47**	URL 1995
ARC 310T02	Fill of chalk involutions			5					10	2	**12**				2			**19**	
ARC PFC 01	Fill of chalk involutions	3957TT		1					3	1	**4**				1			**6**	
ARC PFC 01	Bluelands/Botany	3962SE	6/8	2	1				7	3	**10**							**13**	
ARC 2003 TP	Bluelands/Botany	2003	6/8			1		**1**	3	3	**6**							**7**	URL 1995
ARC PFC 01	Bluelands/Botany	3953TT	6/8						1	1	**2**							**2**	
ARC PFC 01	Bluelands/Botany	3955TT	6/8						1	1	**2**				2			**4**	
ARC PFC 01	Bluelands/Botany	3956TT	6/8							4	**4**							**4**	
ARC PFC 01	Bluelands/Botany	3982TT	6/8	7					12	2	**14**							**21**	
ARC 310 T02	Bluelands/Botany	310T02	6/8	3					9	2	**11**				2			**16**	
Botany Pit	Bluelands/Botany		6/8	273					2450		**2450**				14	95	1005	**3837**	Roe 1968
Esso Pit GCR	Bluelands/Botany		6/8	1					8		**8**							**9**	Bridgland 1994
Greenlands Pit West Face	Bluelands/Botany		6/8	1					9	2	**11**					1		**13**	
Greenlands and Bluelands	Bluelands		6	4					68		**68**		3		1			**76**	Schreve et al 2002
Stonehouse Lane	Bluelands		6/8						6		**6**	1			1			**8**	Essex County Council 1994
Bluelands Pit	Bluelands	3	6	6					57		**57**	100	5				7	**175**	Palmer 1975
Bluelands Pit	Bluelands	1&2	6	8					305		**305**	1147	31		1		113	**1605**	Palmer 1975
Armor Road column	Bluelands		6	1		2	1	**3**	30	29	**59**		2		1	1	3	**70**	
		Subtotals	***8 to 6***	***313***	***3***	***5***	***4***	***9***	***3075***	***97***	***3172***	***1249***	***44***	***0***	***29***	***98***	***1130***	***6047***	

Site	Geology	Trench	Bed number	Flake core	Core frags	Blades	Broken blades	Blades (total)	Flakes	Broken flakes	Flakes (total)	Chips	Scrapers	Projectile points	Handaxes	Debitage	Misc. retouch	Overall Total	Reference
Greenlands and Bluelands	Greenlands shell beds		5						2		**2**							**2**	Schreve et al 2002
Bluelands Pit	Greenlands?	3	5									3						**3**	Palmer 1975
Stonehouse Lane	Greenlands shell beds		3/5						1		**1**							**1**	Essex County Council 1994
Greenlands Pit West Face	Coombe Rock		3/4						4		**4**							**4**	
Greenlands and Bluelands	Shelly/Little Thurrock		3						2		**2**							**2**	Schreve et al 2002
Bluelands Pit	Shelly gravel	1&2	3										1					**1**	Palmer 1975
Greenlands Pit West Face	Shelly gravel		3						1		**1**							**1**	
Armor Road column	Shelly gravel		3						8		**8**	7						**15**	
		Subtotals	***5 to 3***						***18***		***18***	***10***	***1***					***29***	
ARC PFC 01	Little Thurrock	3953TT	2						2	2	**4**							**4**	
ARC PFC 01	Little Thurrock	3954TT	2	2					7	2	**9**		1				1	**13**	
Greenlands Pit West Face	Little Thurrock		2	2					3	6	**9**	3				2		**16**	
Armor Road column	Little Thurrock		2						4	1	**5**							**5**	
Bluelands Pit	Little Thurrock	3	2									9					2	**11**	Palmer 1975
Greenlands and Bluelands	Coombe Rock		1	2					6		**6**							**8**	Schreve et al 2002
		Subtotals	***2 to 1***	***6***					***22***	***11***	***33***	***12***	***1***			***2***	***3***	***57***	
			Grand Totals	**332**	**4**	**24**	**24**	**48**	**3317**	**224**	**3541**	**1281**	**48**	**3**	**30**	**100**	**1136**	**6523**	

Table 9

Table 9: Details of the (proto) Levallois cores from the HS1

Context	kg	Flint	Platform	Flaking face removals	Max flake face mm	Type	1	2	3	4	5	6	Size
ARC 310 T02 Bed 6/8) Inv.	2.03	Nodule	Negative facet	3 3	123	Bifacial/Hx roughout	✓					✓	187 x 144 x 88
ARC 310 T02 Bed 6/8) Inv.	2.39	Nodule Bullhead	Alternate flaking	15	70	Bifacial	✓					✓	175 x 145 x 73
ARC 310 T02 Bed 6/8) Inv.	0.63	Nodule Bullhead	Alternate flaking	8	70	Migrating platform/ Sub-biconical	✓					✓	108 x 86 x 73
ARC 310 T02 Bed 6/8) Inv.	2.58	Nodule	Prepared	2	110	Proto/reduced Levallois	✓	✓		✓	✓	✓	192 x 119 x 97
ARC 310 T02 Bed 6/8) Inv.	1.73		Alternate flaking	17	115	Discoidal/Biconical	✓				✓?	✓	148 x 144 x 82
ARC 310 T02 Bed 6/8)	1.44	Nodular marbled			115	Migrating platform/Bifacial	✓					✓	
ARC 310 T02 Bed 6/8)	0.83	Fragment marbled				Migrating platform/ Unclassed							
ARC 310 T02 Bed 6/8)	1.07	Nodule	Prepared	7	70	Proto/reduced Levallois/adjacent	✓	✓		✓	✓	✓	148 x 133 x 48
3982TT (Bed 6/8)	0.30	Fragment		3		Migrating platform/ Alternate flaking							
3982TT (Bed 6/8)	0.34	Nodule fragment	Thermal	2	80	Migrating platform/ Unclassed							80 x 102 x 52
3982TT (Bed 6/8)	0.53	Nodule	Prepared		70	Migrating/opposed platform							98 x 83 x 69
3982TT (Bed 6/8)	1.59	Cylindrical nodule	Prepared	3	89	Proto/reduced Levallois/ unipolar parallel	✓	✓		✓	✓	✓	106 x 105 x 139
3982TT (Bed 6/8)	1.52	Nodule Bullhead	Prepared	4 and 1	76	Proto/reduced Levallois/ unipolar parallel	✓	✓		✓	✓	✓	130 x 99 x 75
3982TT (Bed 6/8)	0.34	Marbled	Prepared	2 and 1	83	Proto/reduced Levallois	✓	✓		✓	✓	✓	96 x 77 x 38
3982TT (Bed 6/8)	0.94	Nodule	Prepared	4 and 2	100	Proto/reduced Levallois/ opposed platform	✓	✓		✓	✓	✓	146 x 122 x 61

Note: Inv. = from involutions in the top of the chalk

Table 10: Statistical summary of the stable isotopic data from the Purfleet oncoids

	$\Delta^{18}O$ (‰ PDB)	**$\Delta^{13}C$ (‰ PDB)**
Mean	-7.04	-8.49
Median	-6.97	-8.55
Standard Deviation	0.24	0.16

Table 11: Summary of Purfleet carbonate isotopic data, compared with that from a modern carbonate system (River Gipping, Suffolk)

	$\Delta^{18}O$ (‰ PDB) Purfleet	$\Delta^{18}O$ (‰ PDB) Gipping	$\Delta^{13}C$ (‰ PDB) Purfleet	$\Delta^{13}C$ (‰ PDB) Gipping
N	15	22	15	22
Mean	-7.04	-7.02	-8.49	-7.73
Median	-6.97	-7.17	-8.55	-7.69
Standard Deviation	0.24	0.44	0.16	1.31

Table 12

Table 12: **Raw isotopic data from Purfleet shell samples (ESSO Sports Field site)**

Sample	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)
CC62588/PF1	-11.33	-5.96
CC62589/PF2	-10.94	-6.11
CC62590/PF3	-10.77	-5.98
CC62591/PF4	-11.93	-5.96
CC62592/PF5	-12.04	-5.97
CC62593/PF6	-11.95	-5.91
CC62594/PF7	-11.25	-6.11
CC62595/PF8	-10.71	-6.08
CC62596/PF9	-10.69	-6.02
CC62597/PF10	-10.27	-5.82
Mean	-11.99	-5.99
Standard Deviation	-0.62	-0.1

Table 13: Summary of OSL dating from the Greenlands Quarry west face (see Fig. 15)

Field code	Lab. code	Stratigraphical sequence (rank order)	Bed No.	De (Gy)	Dose rate (mGyla)	Age estimate code	Age (ka)
PFGO1-05-WF	X805	6	9	150 ± 17	0.97 ± 0.05	OxL-1275	154 ± 19
PFGO1-03-WF	X803	4=	6/8	196 ± 8	0.61 ± 0.03	OxL-1273	323 ± 23
PFGO1-04-WF	X804	4=	6/8	169 ± 23	0.58 ± 0.03	OxL-1274	292 ± 43
PFGOl-Ol-WF	X801	2=	5	123 ± 6	0.30 ± 0.02	OxL-1271	405 ± 27
PFGO1-02-WF	X802	2=	5	115 ± 19	0.32 ± 0.02	OxL-1272	360 ± 62
Lam sed 5.10.01-WF	X839	1	4	215 ± 26	0.81 ± 0.06	OxL-1276	267 ± 38

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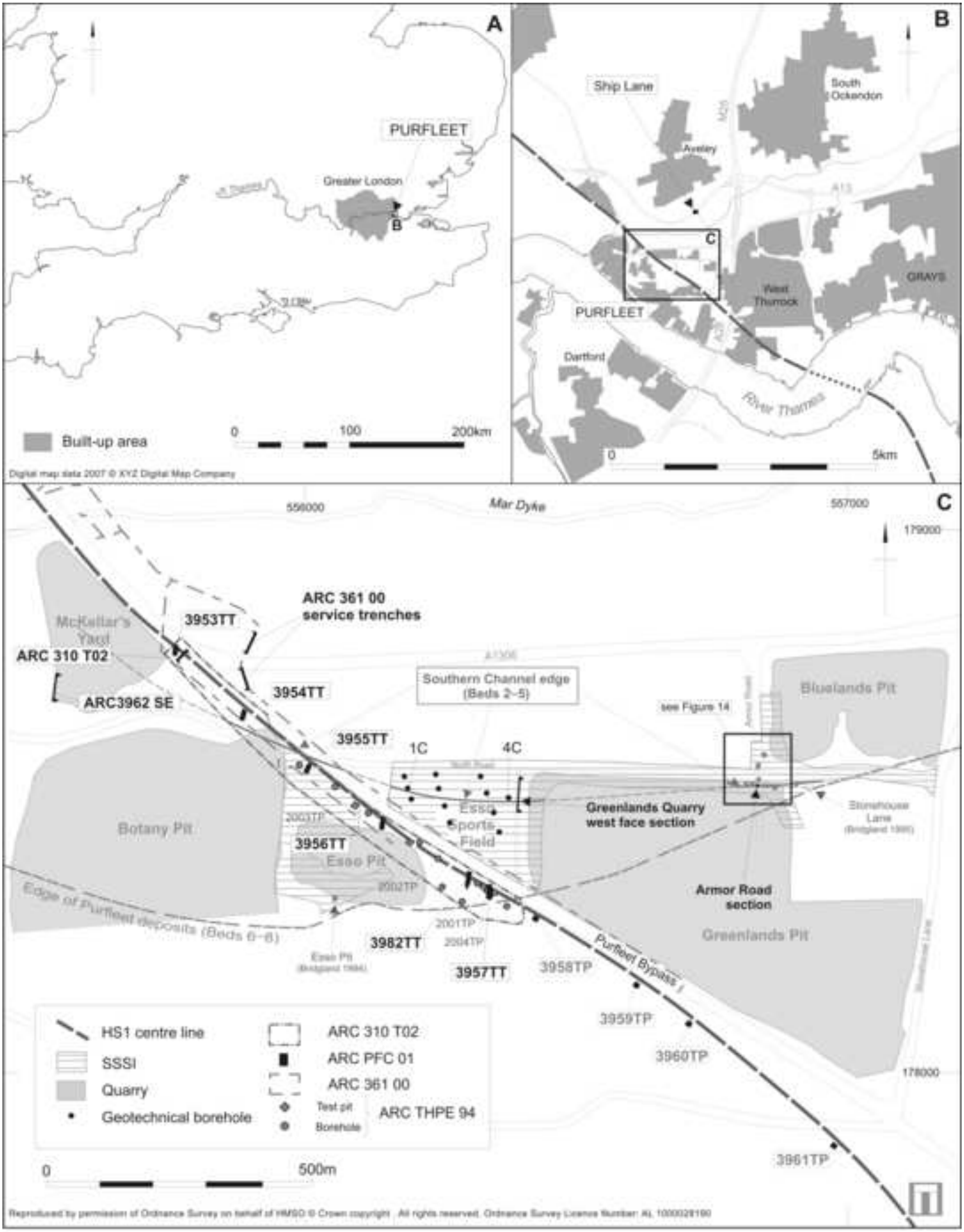

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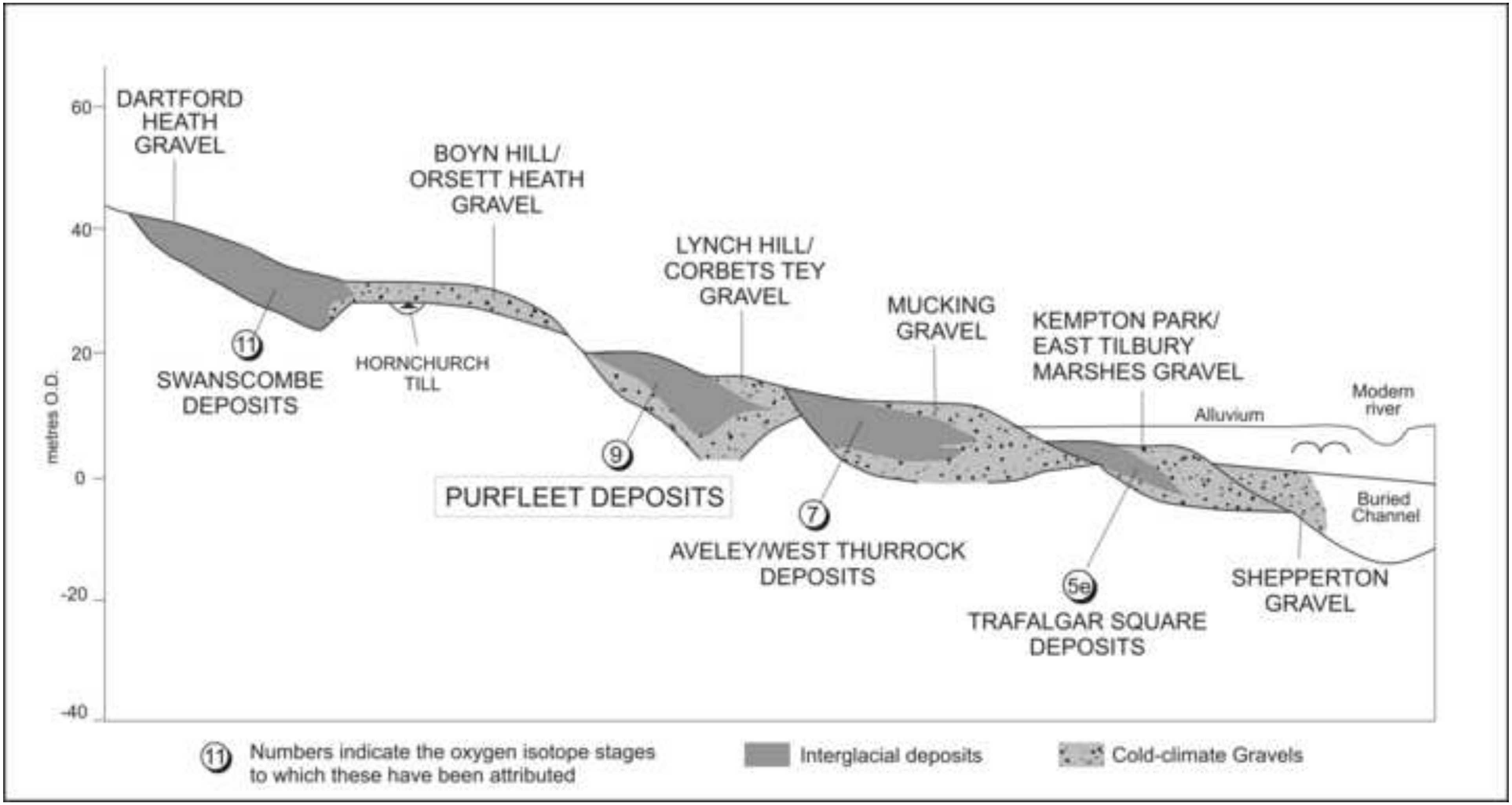

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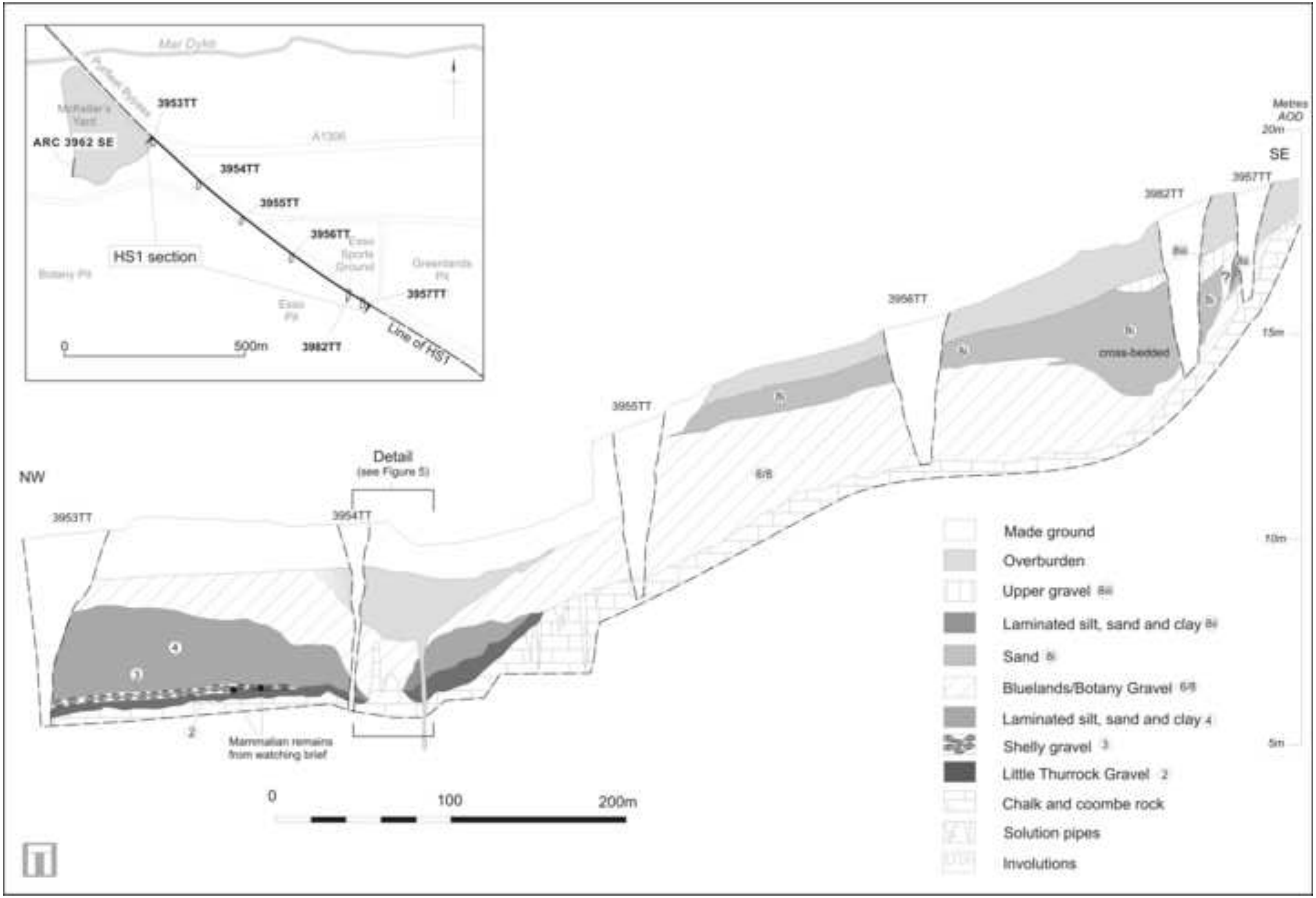

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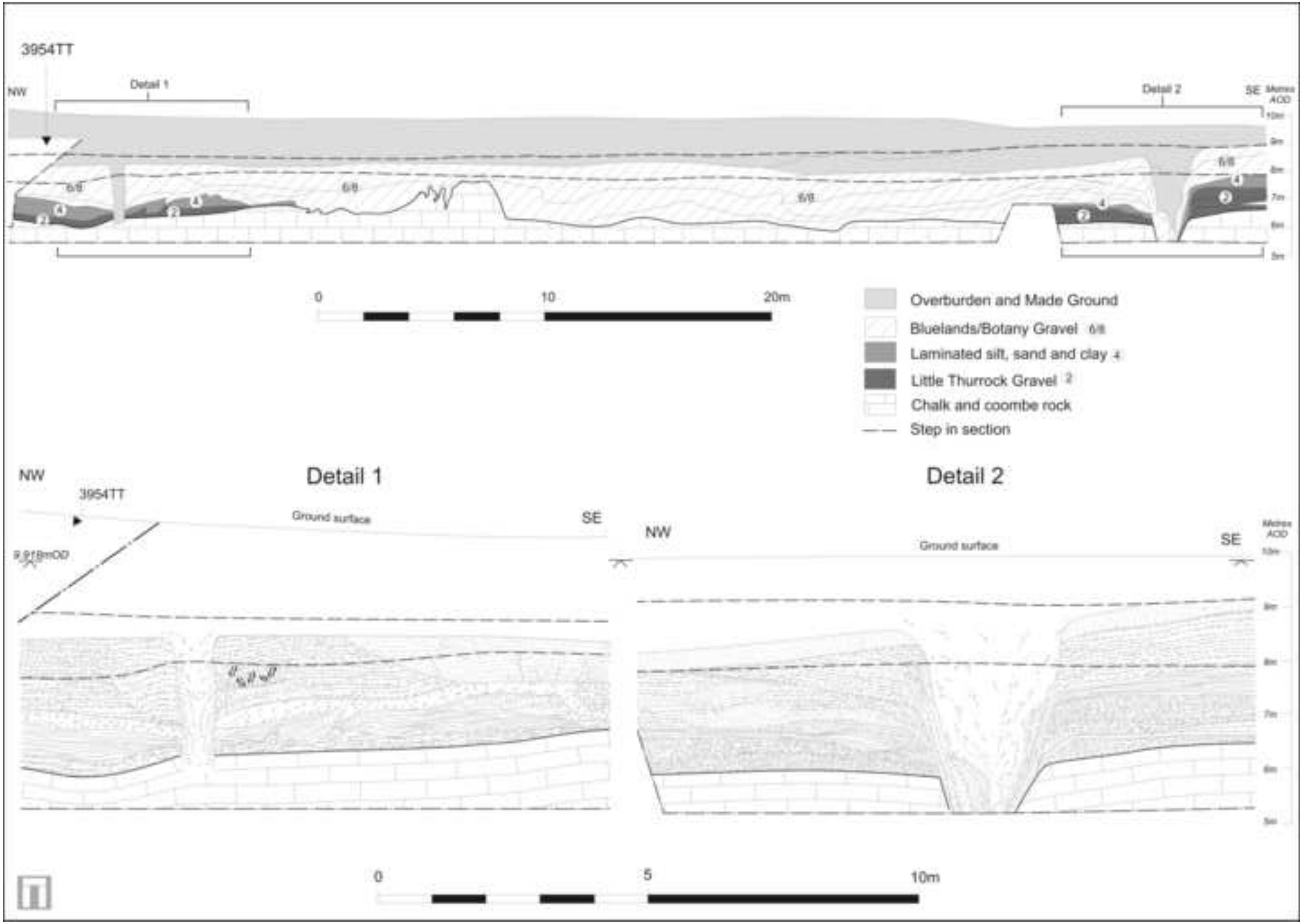

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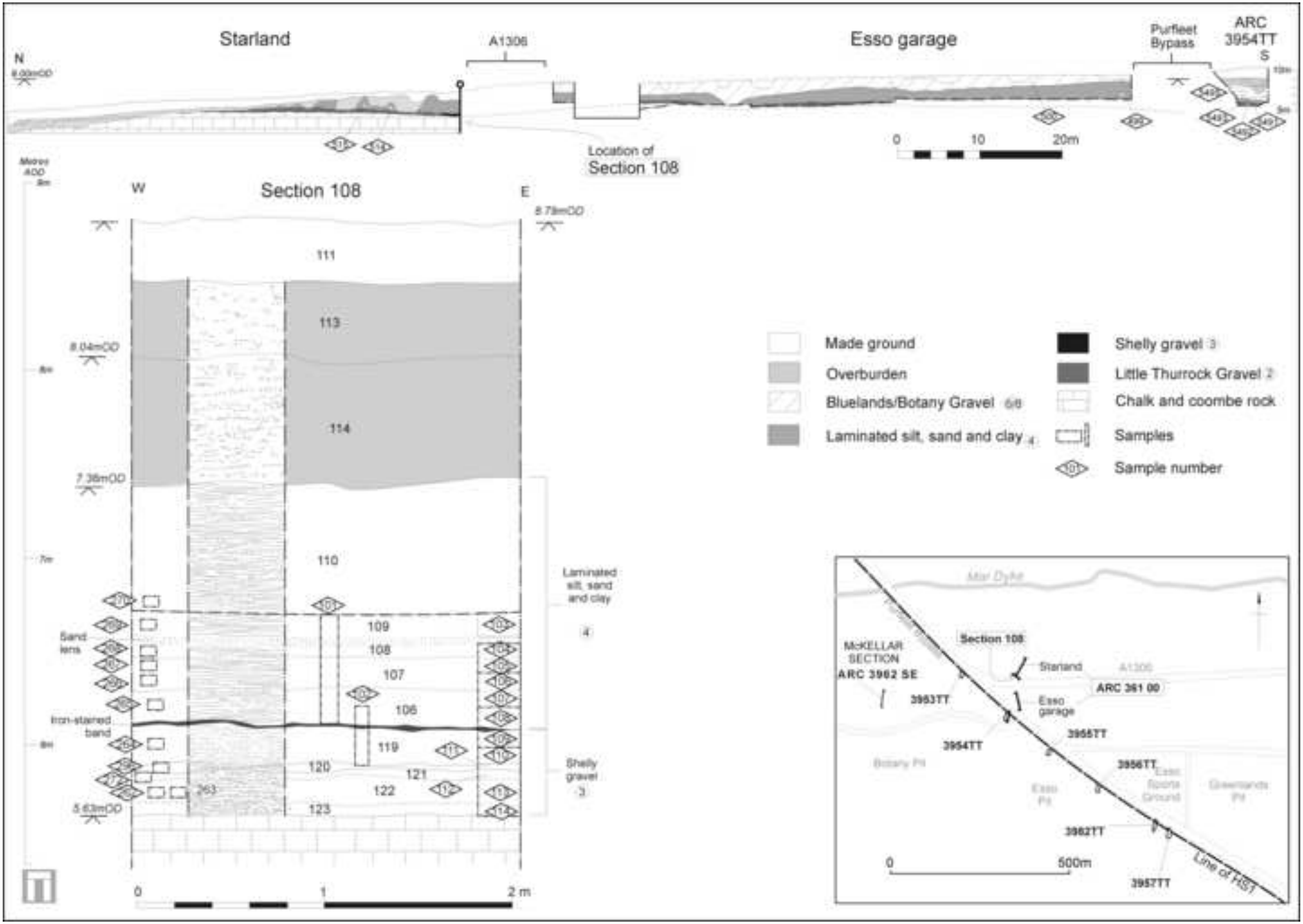

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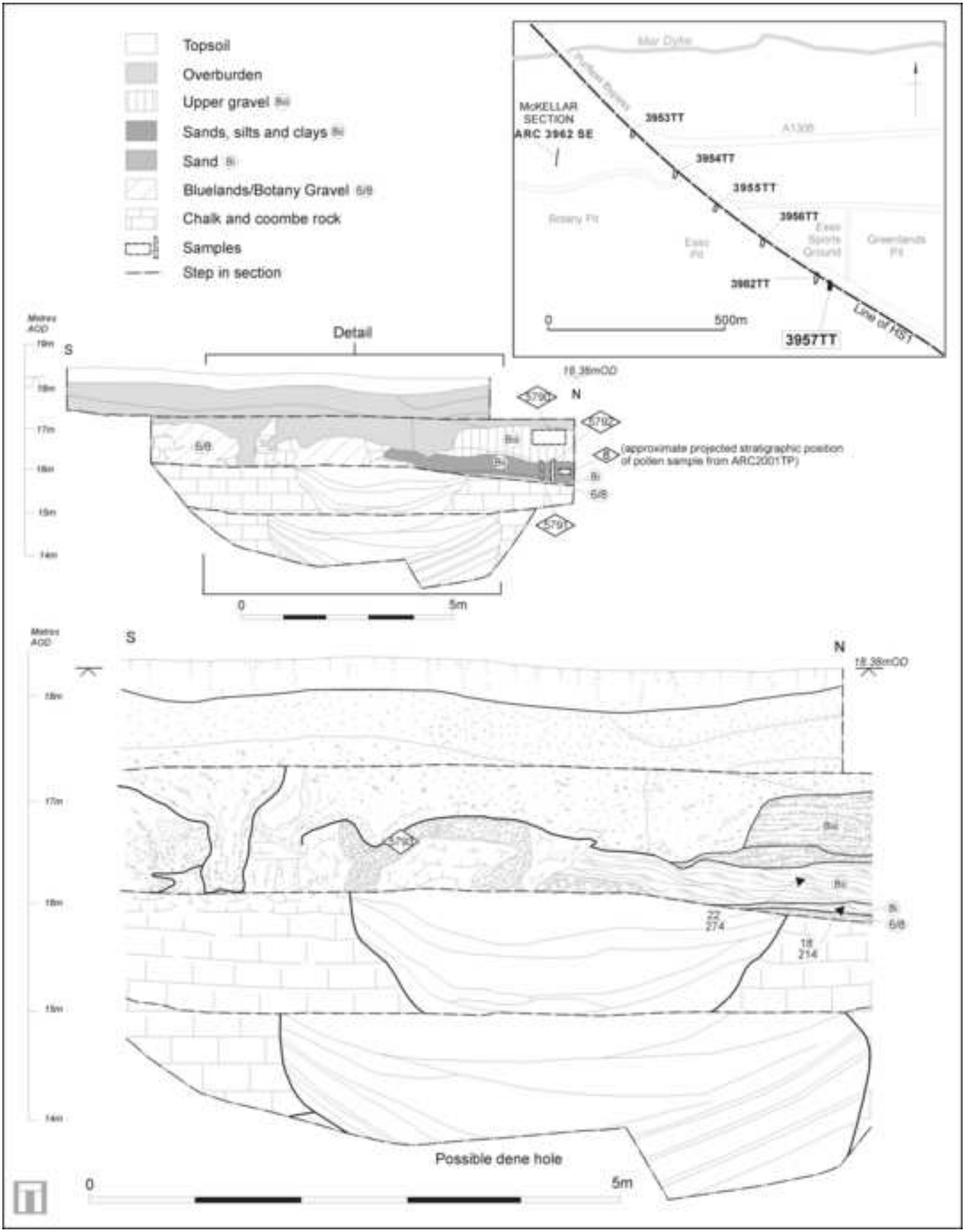

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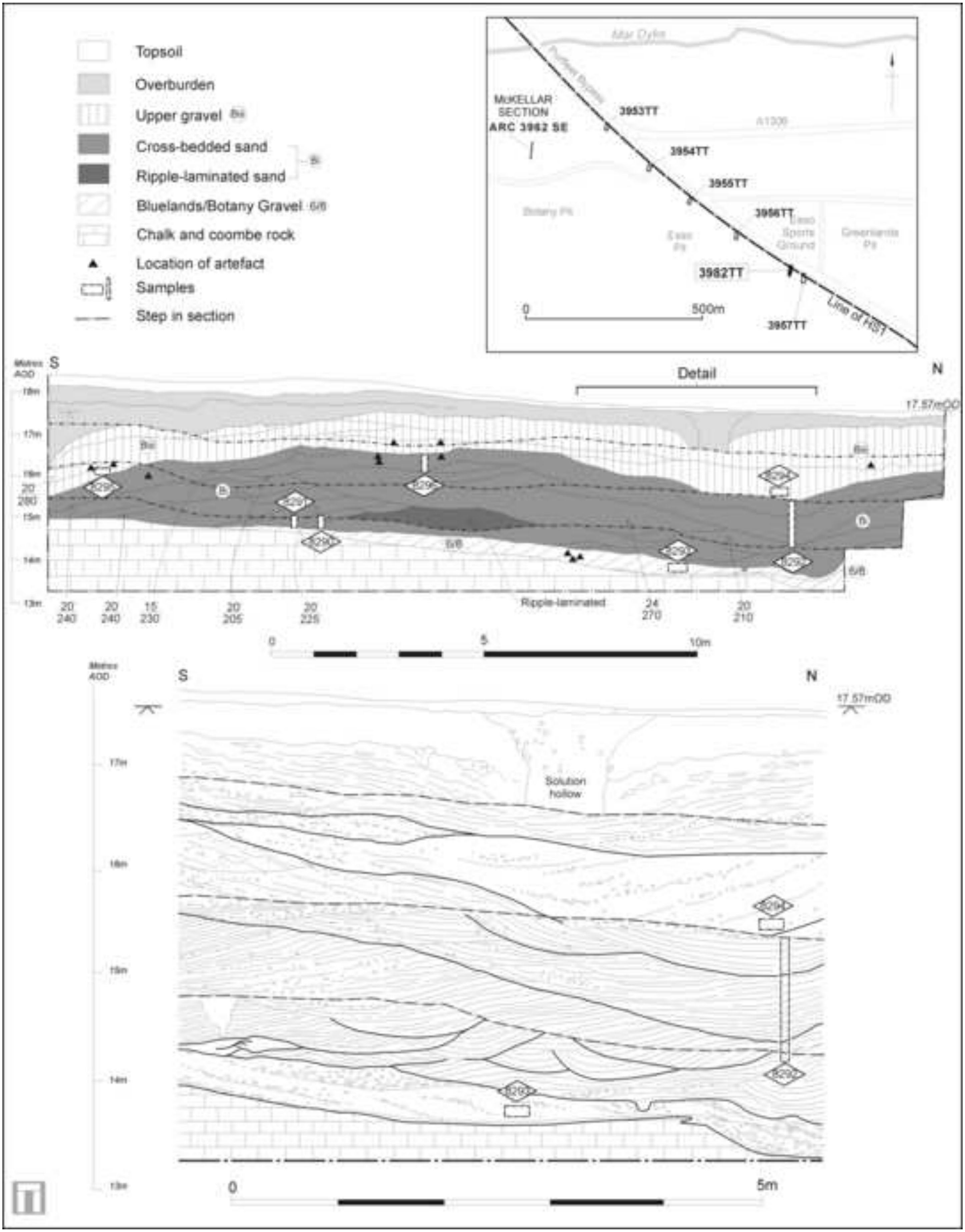

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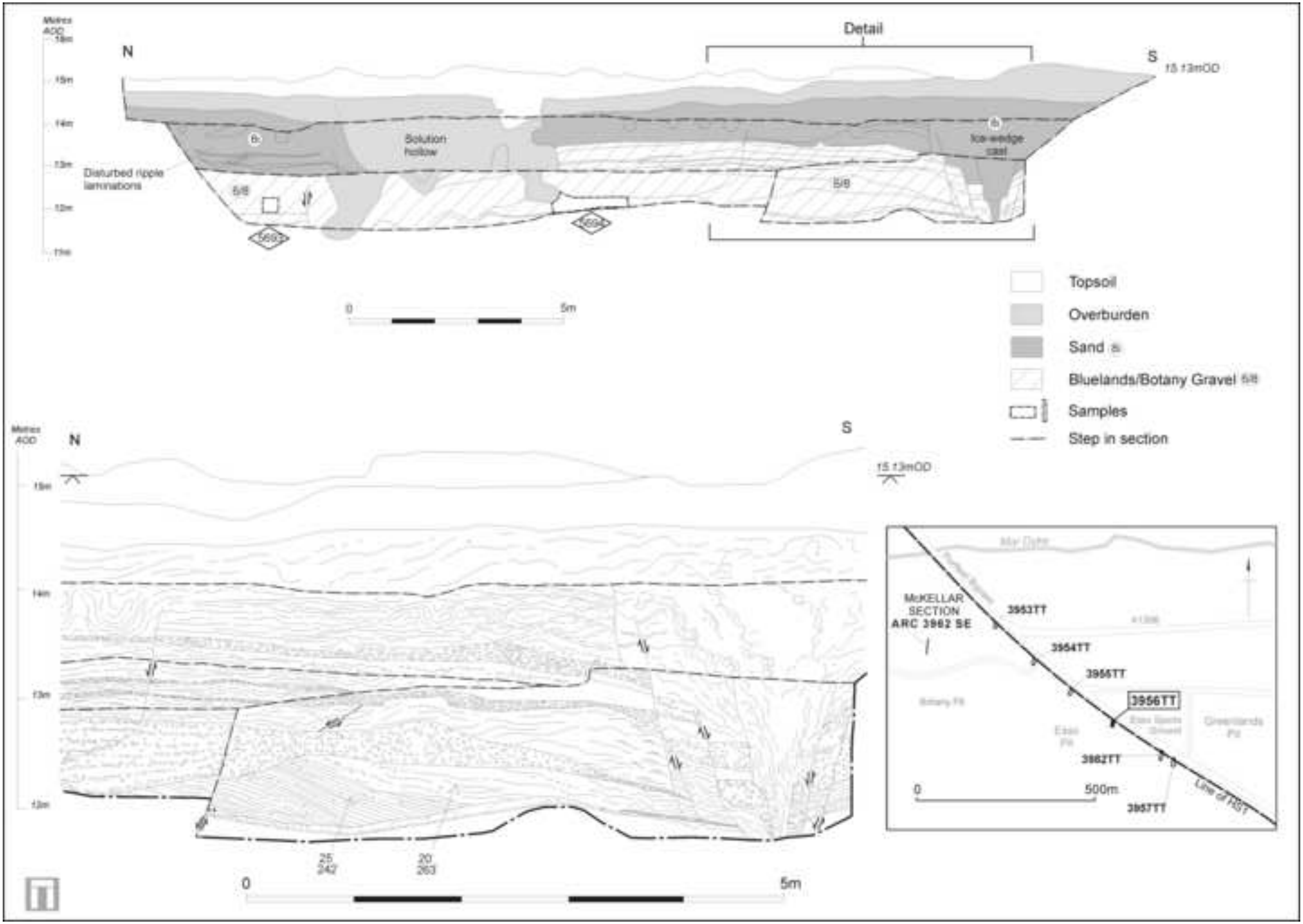

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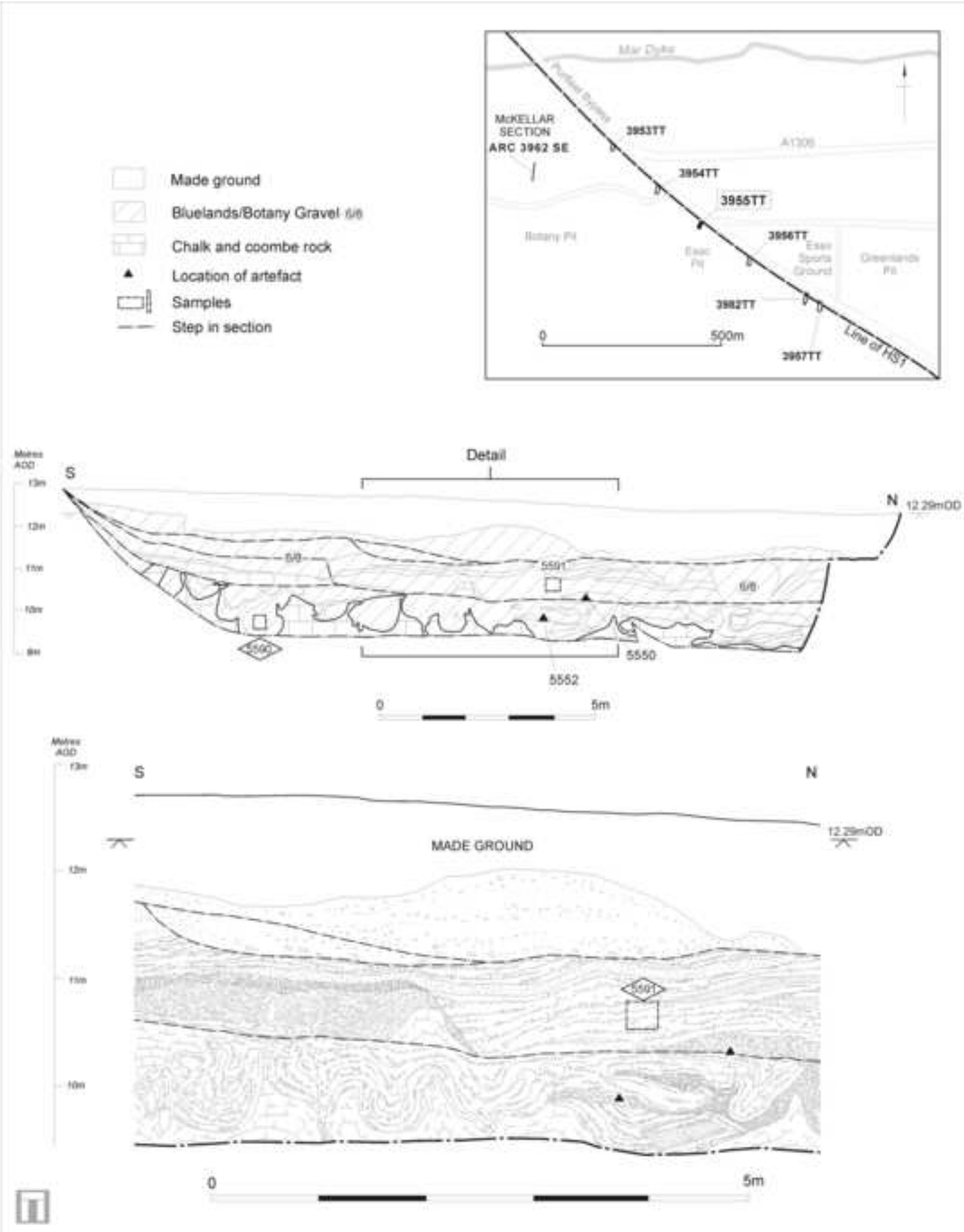

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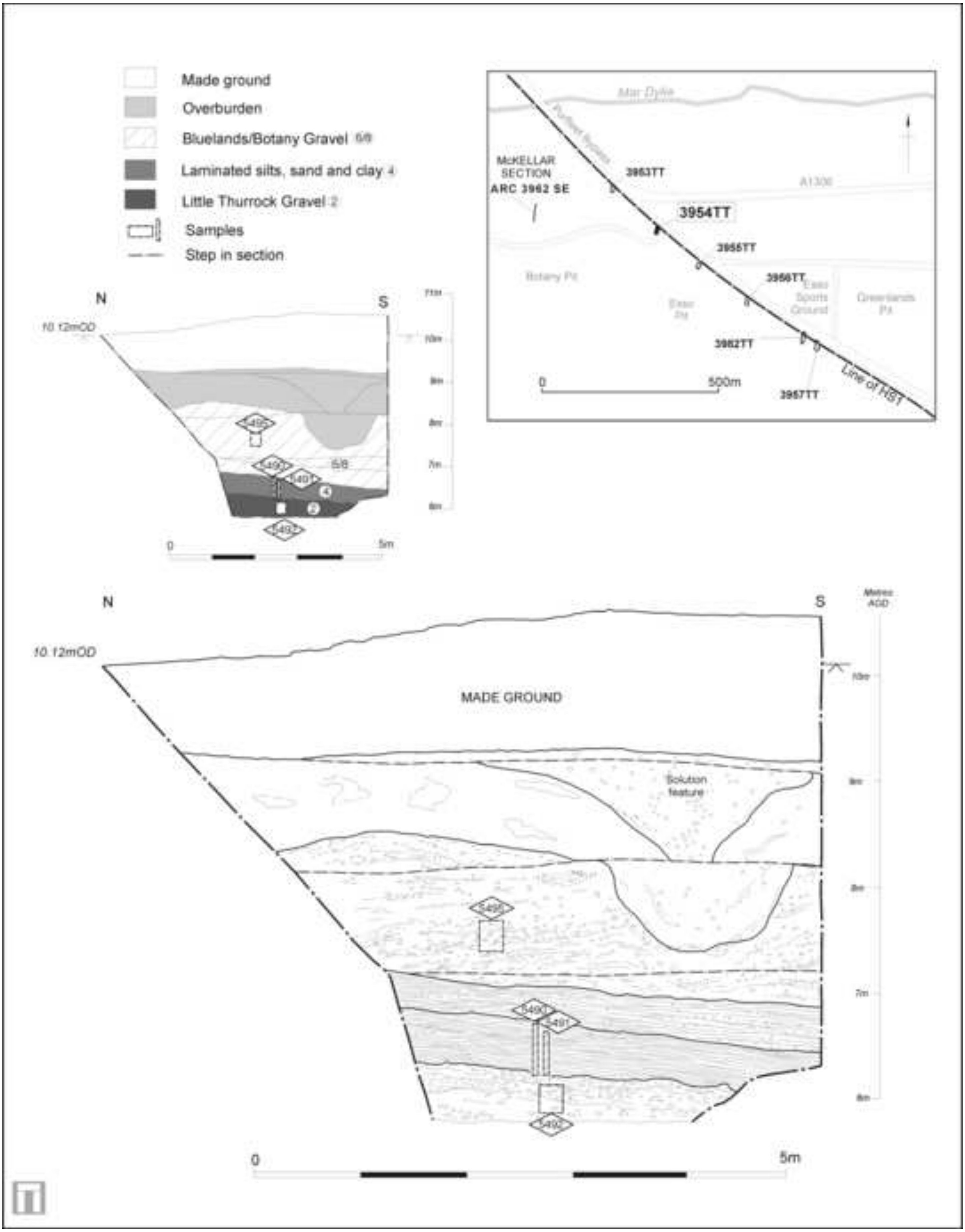

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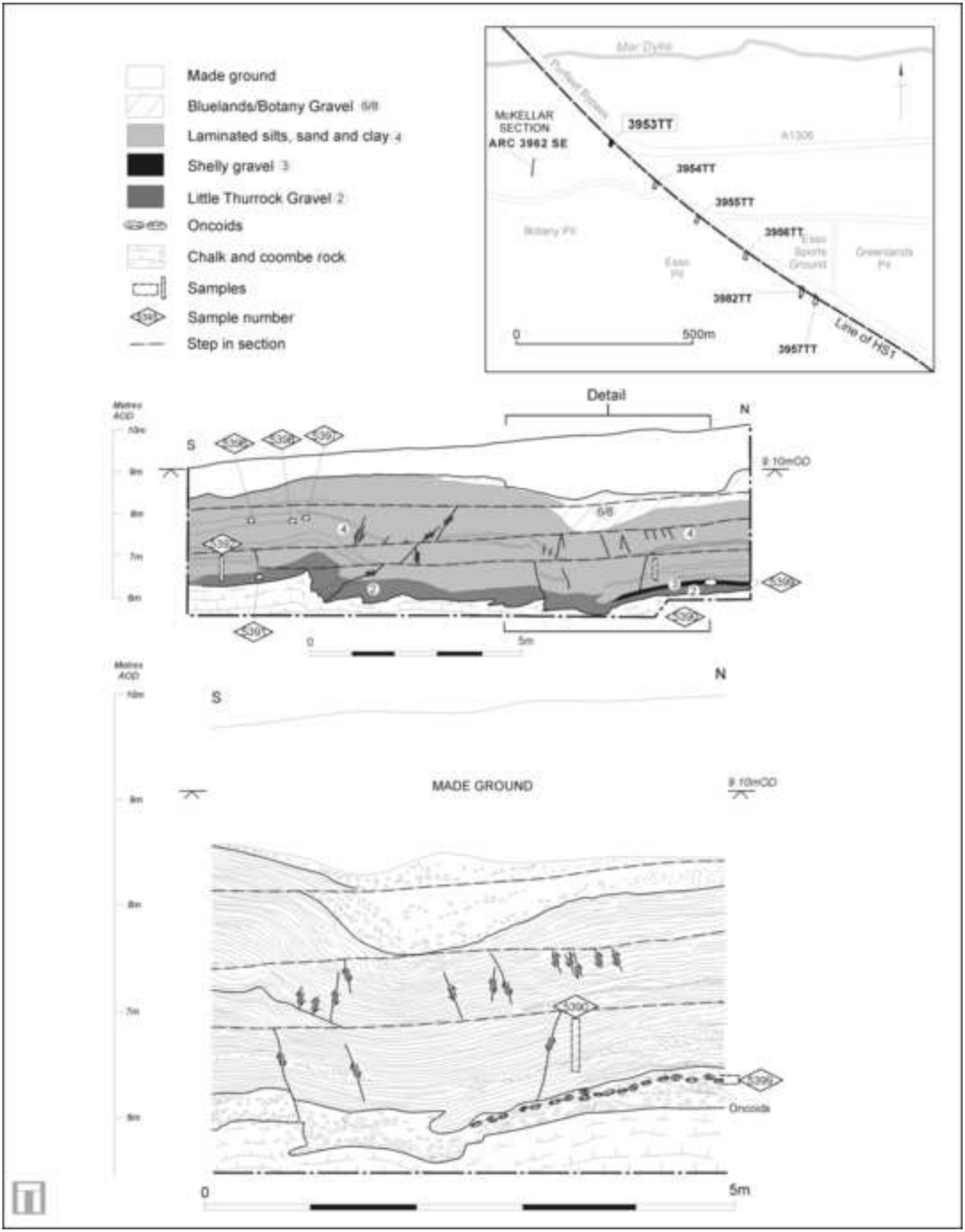

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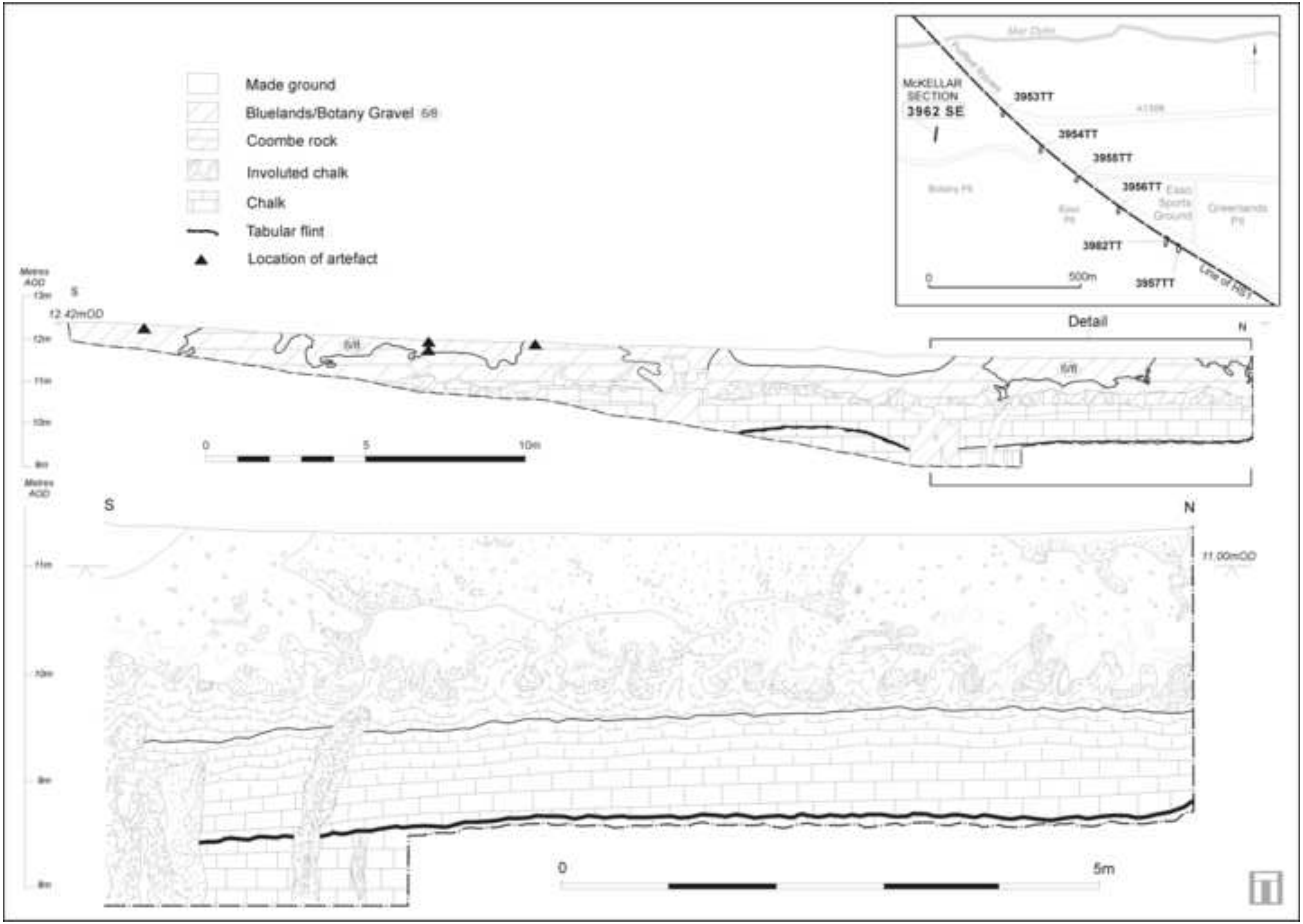

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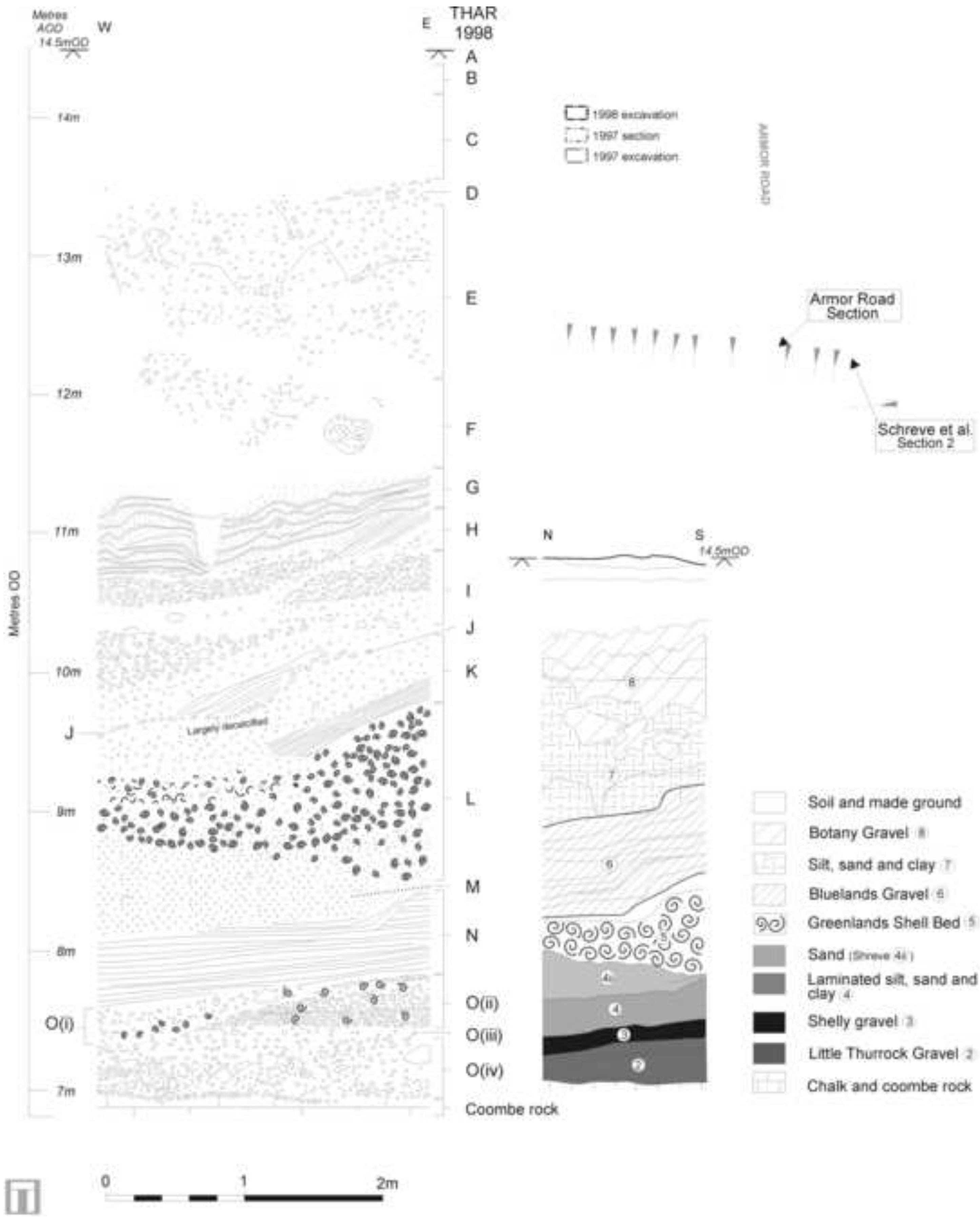

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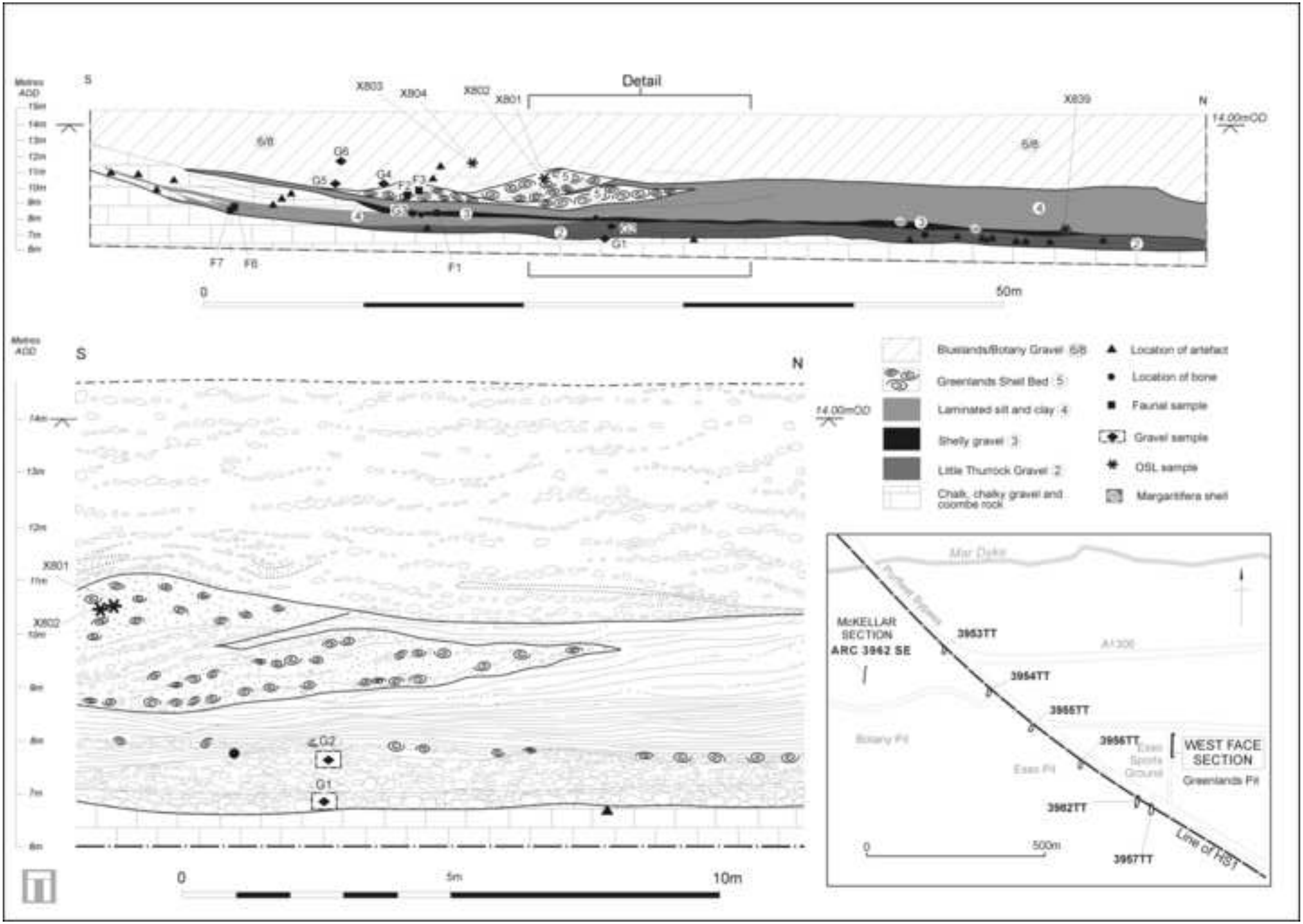

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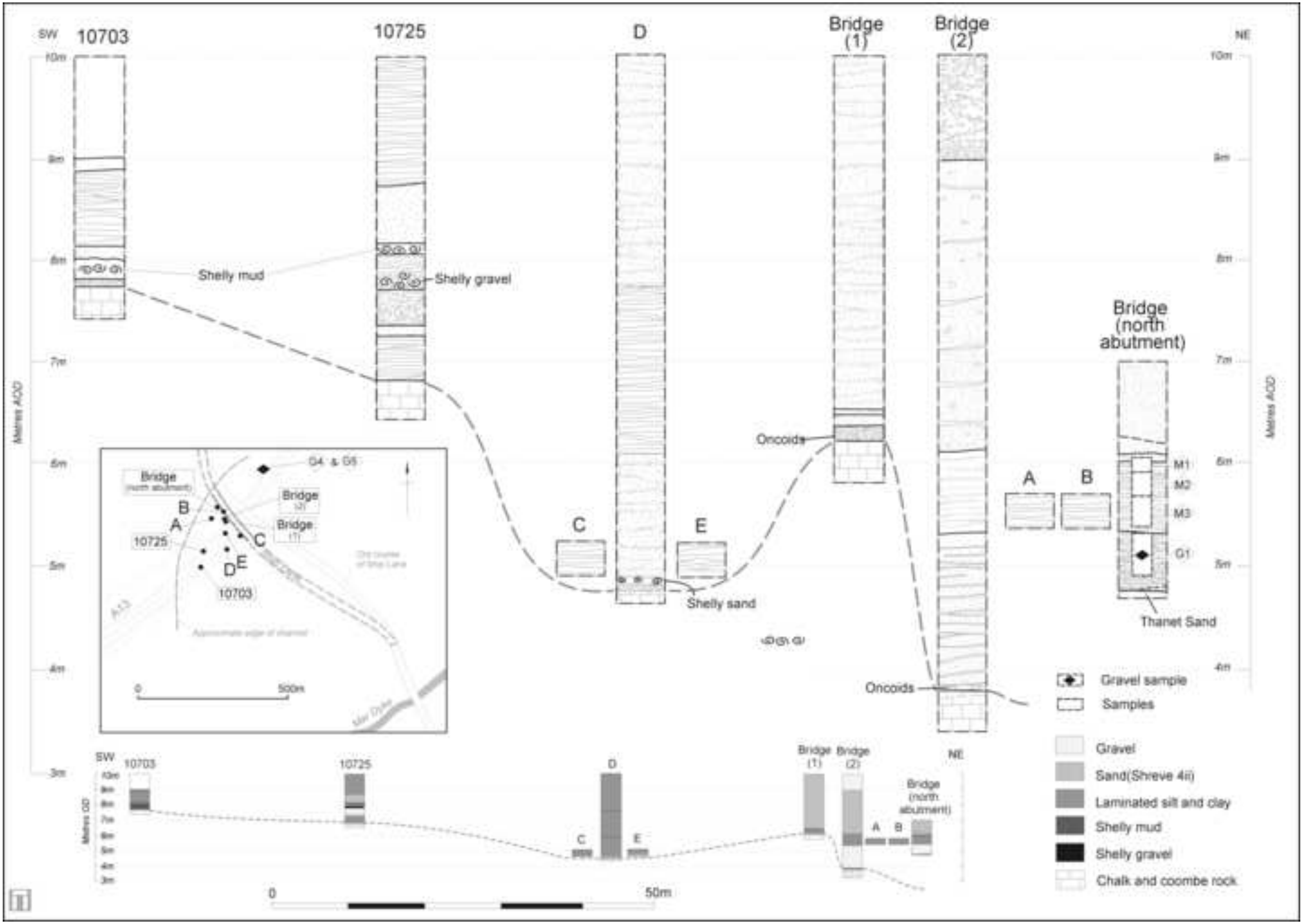

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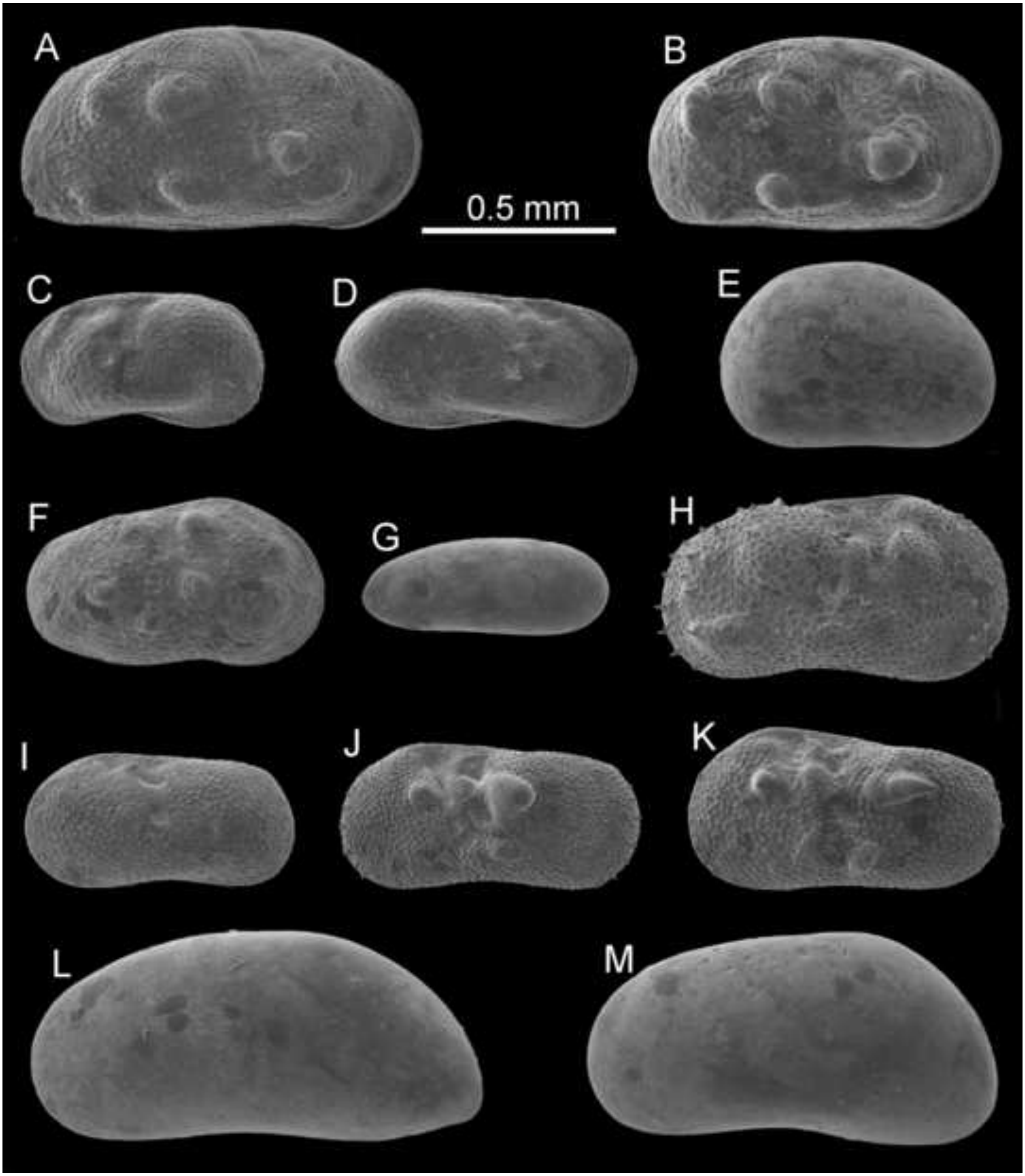

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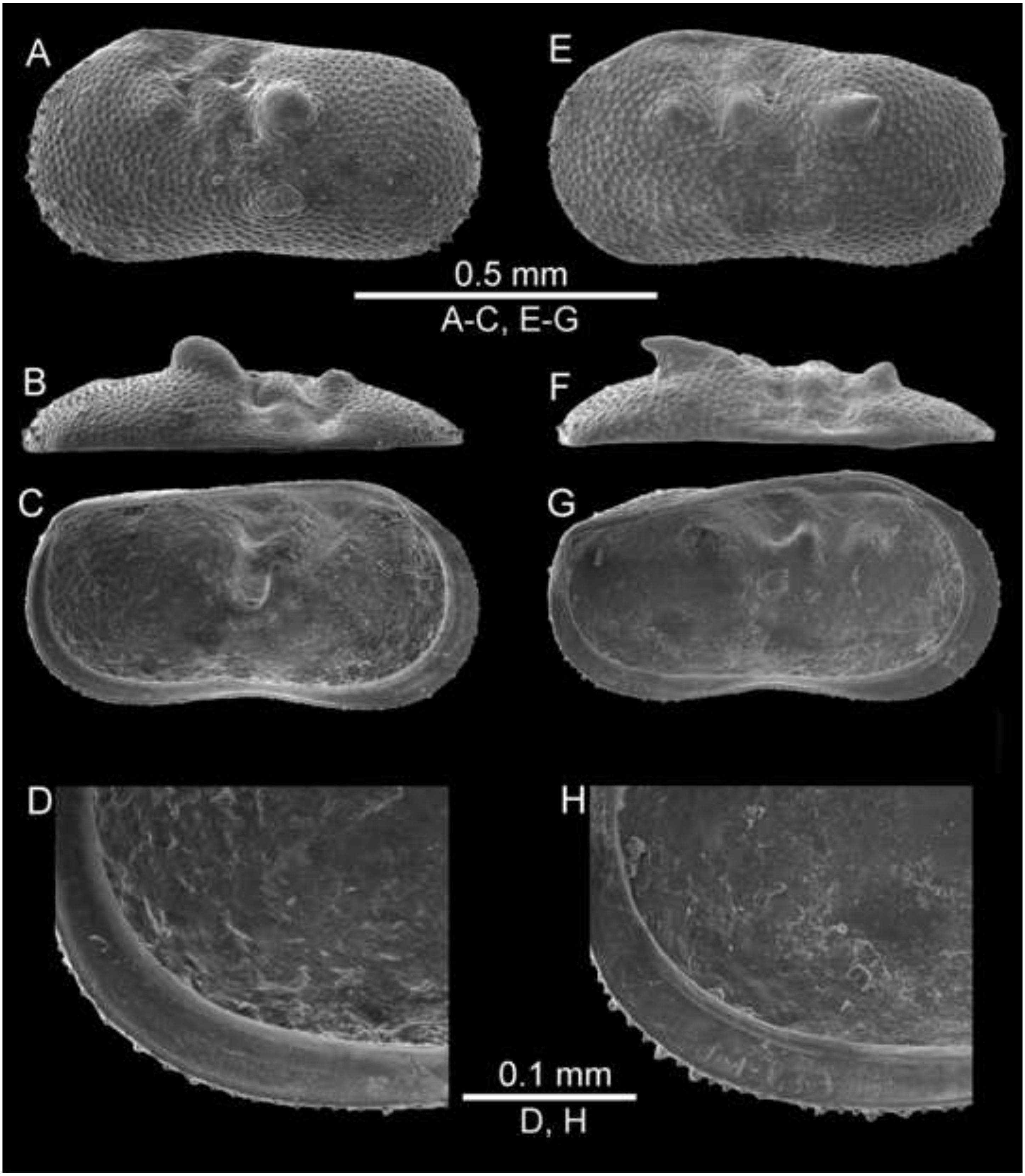

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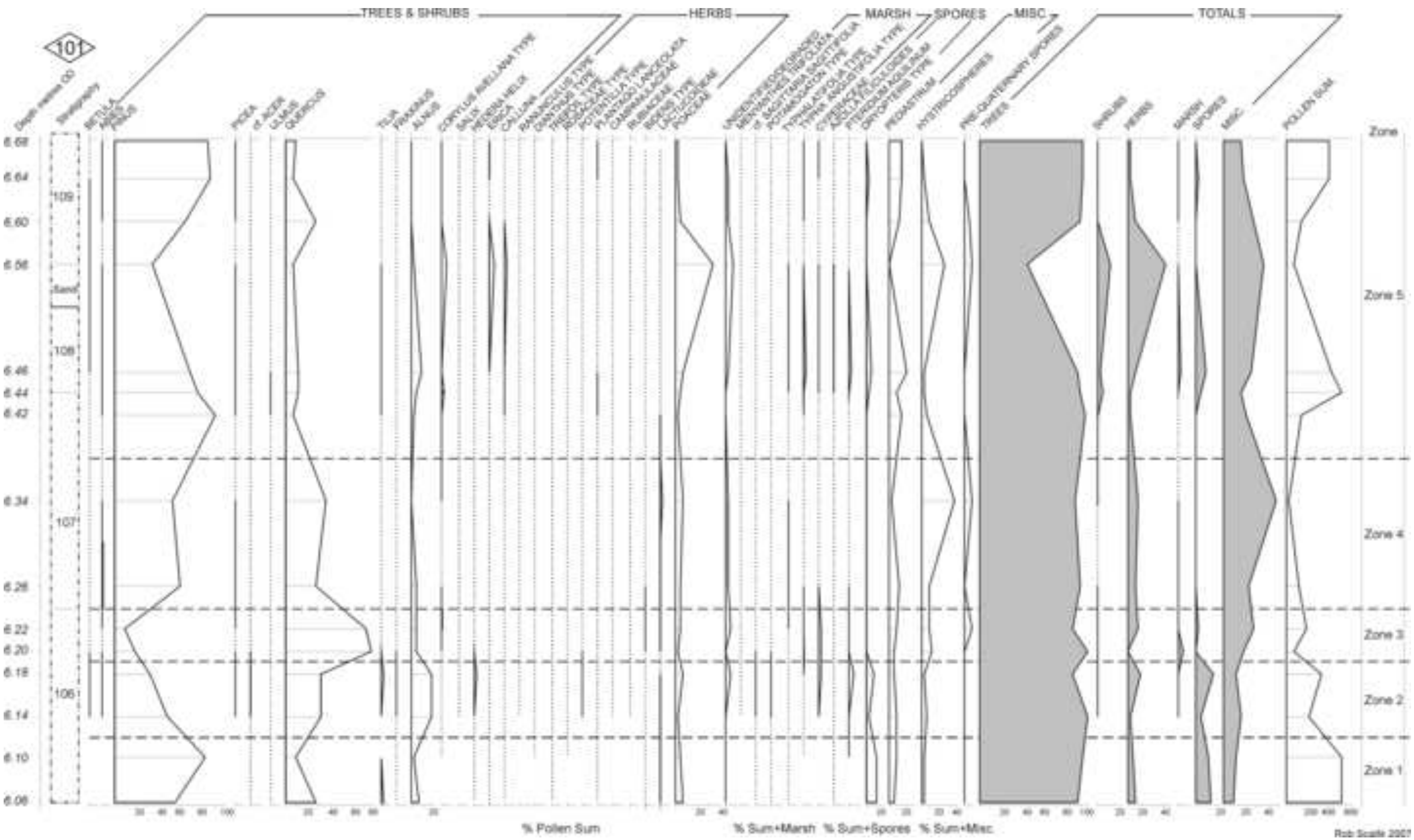

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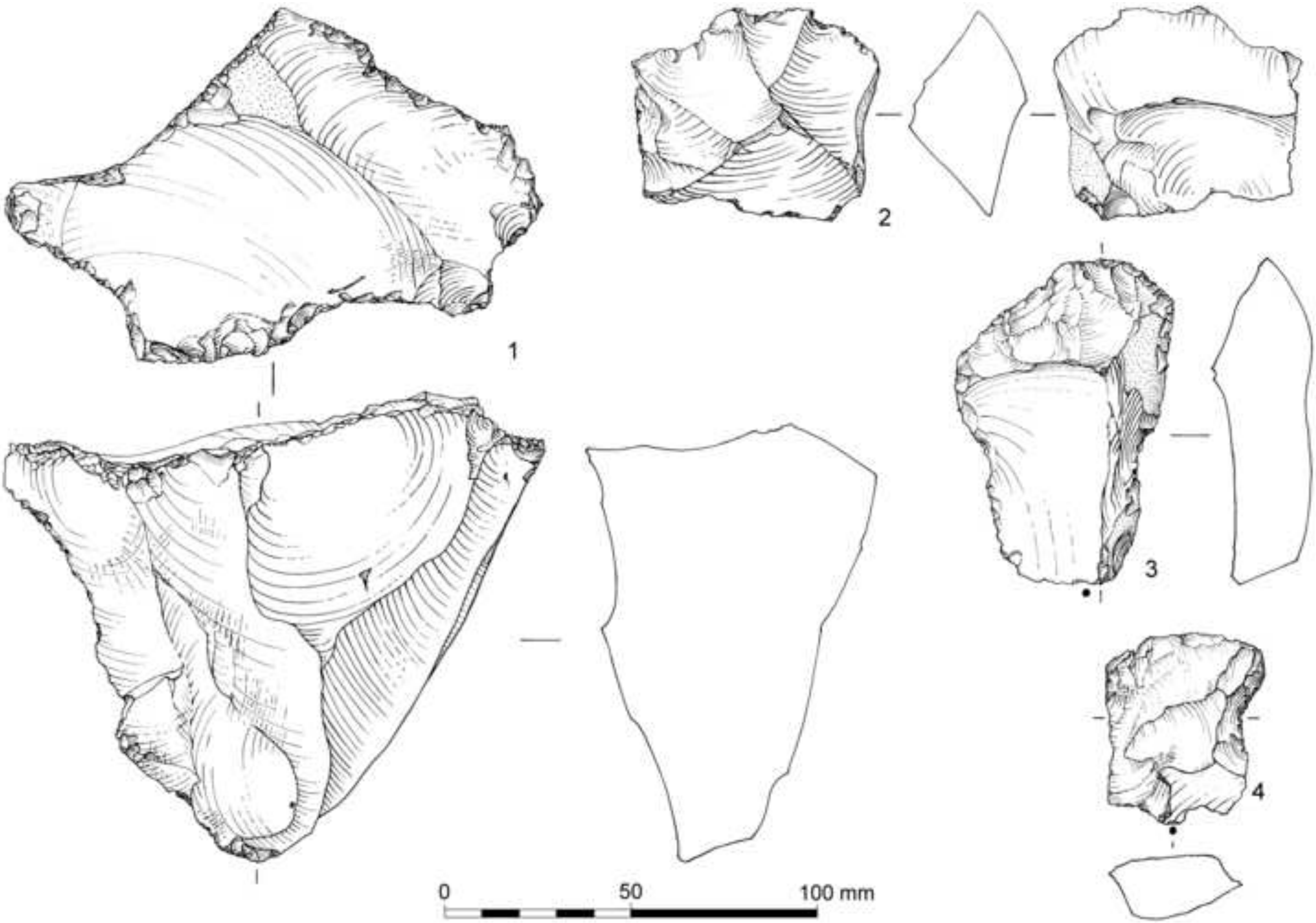

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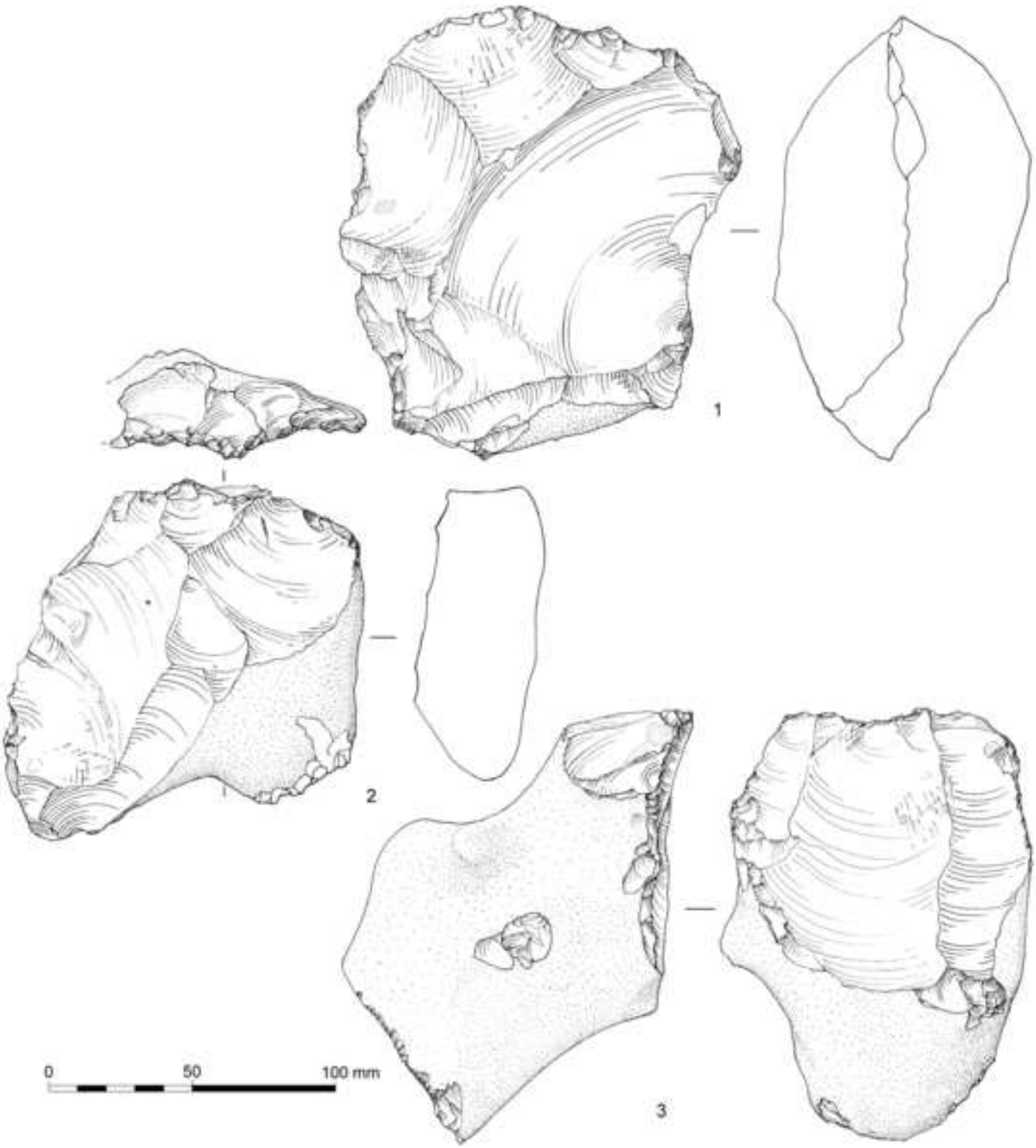

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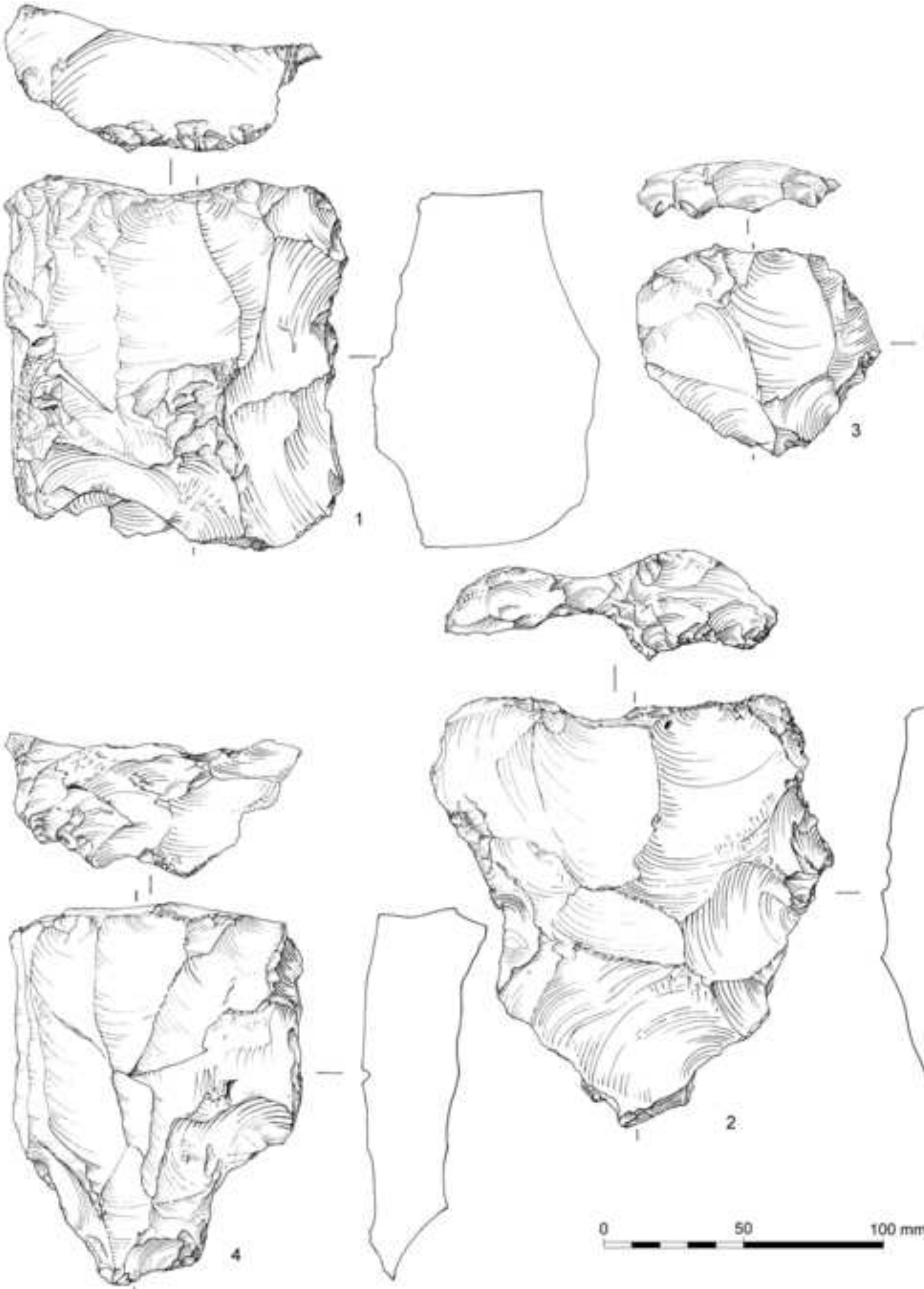

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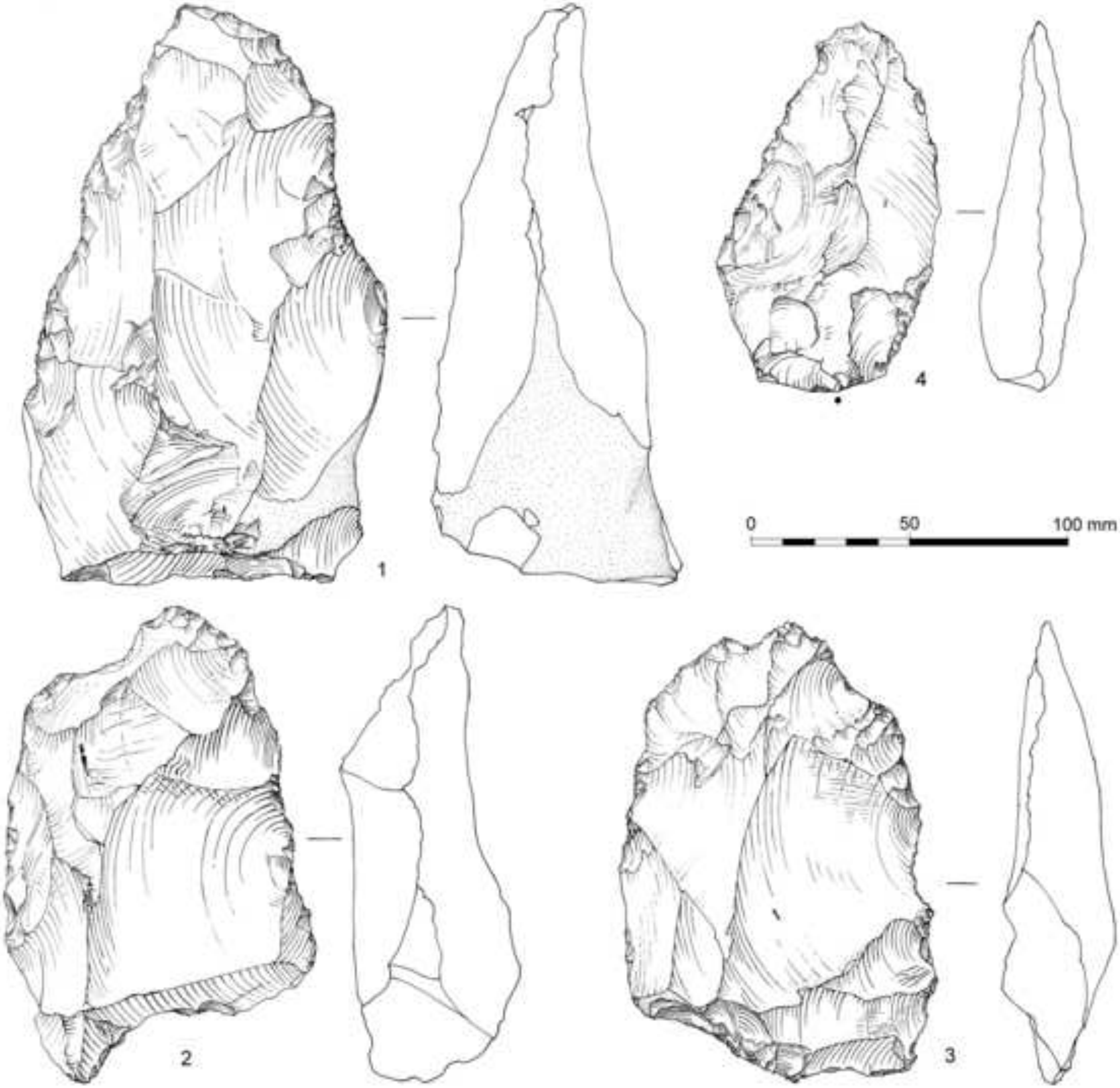

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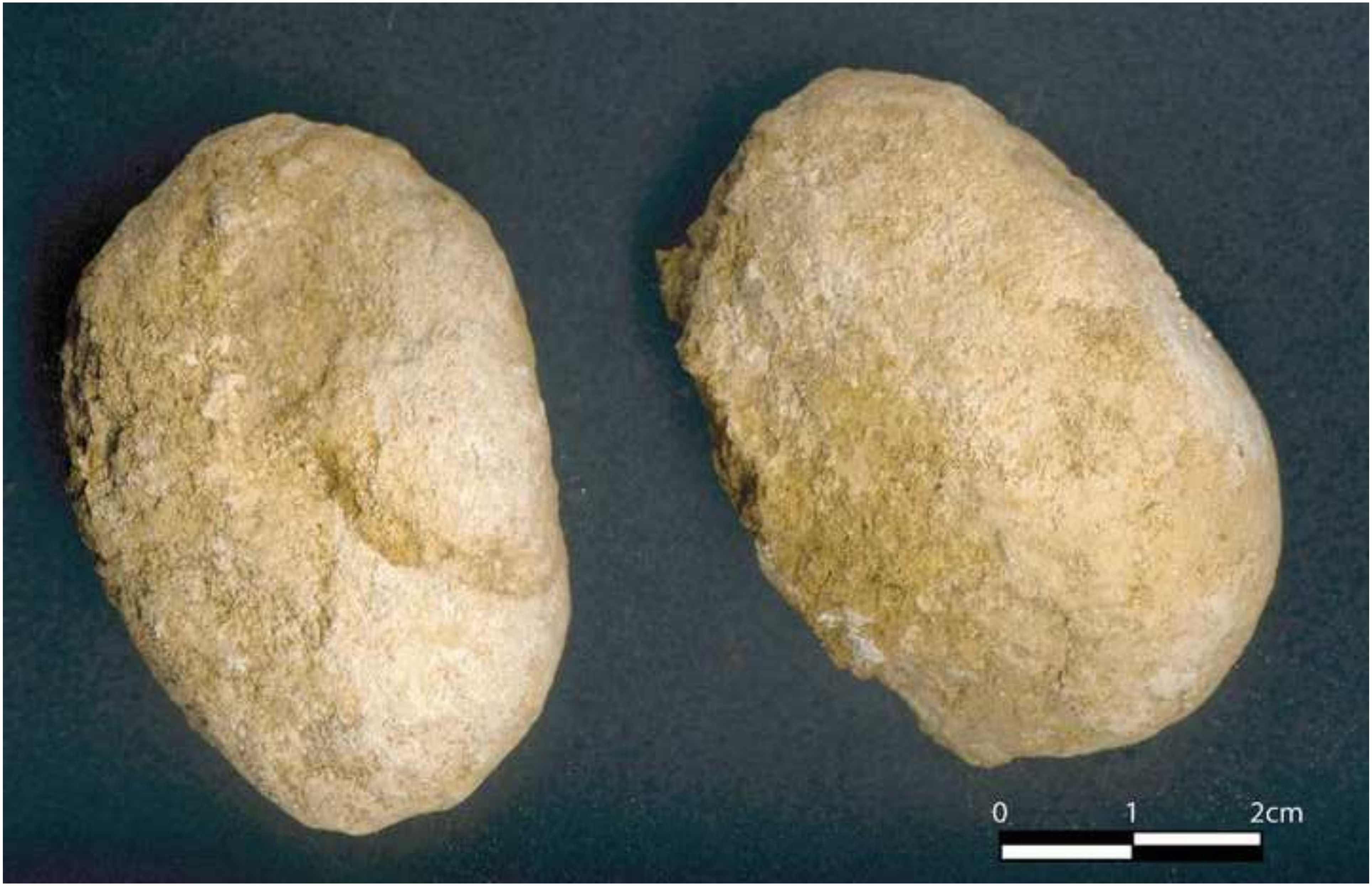

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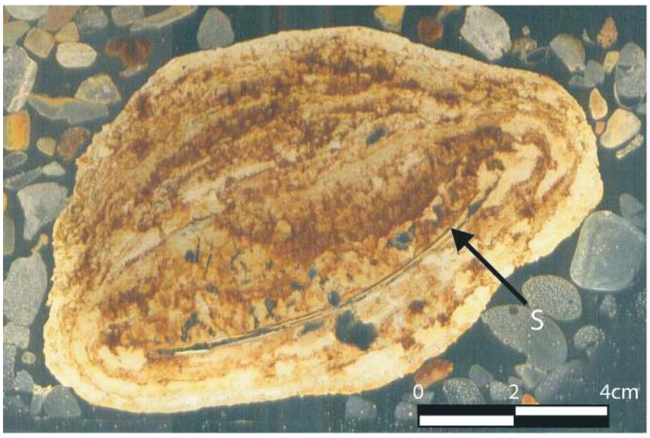

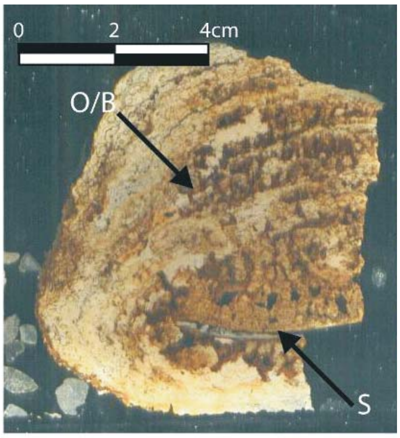

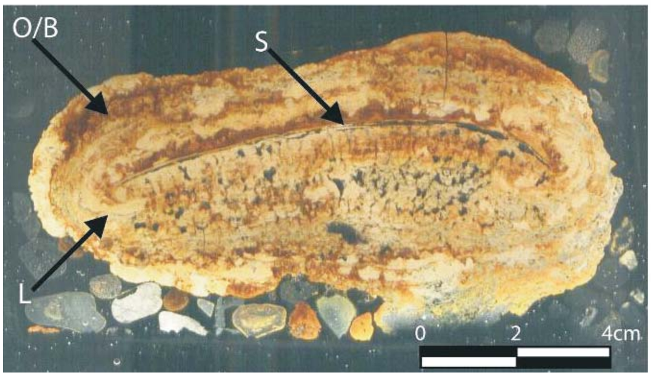

Fig. 26 – Micrographs showing the internal structure of three of the Purfleet carbonate concretions. In each case a bivalve shell (labelled S) core is surrounded by accumulations of secondary carbonate. The two significant micromorphological characteristics of these concretions are (1) weak internal laminations (L) and (2) zones of orange/brown staining (O/B).

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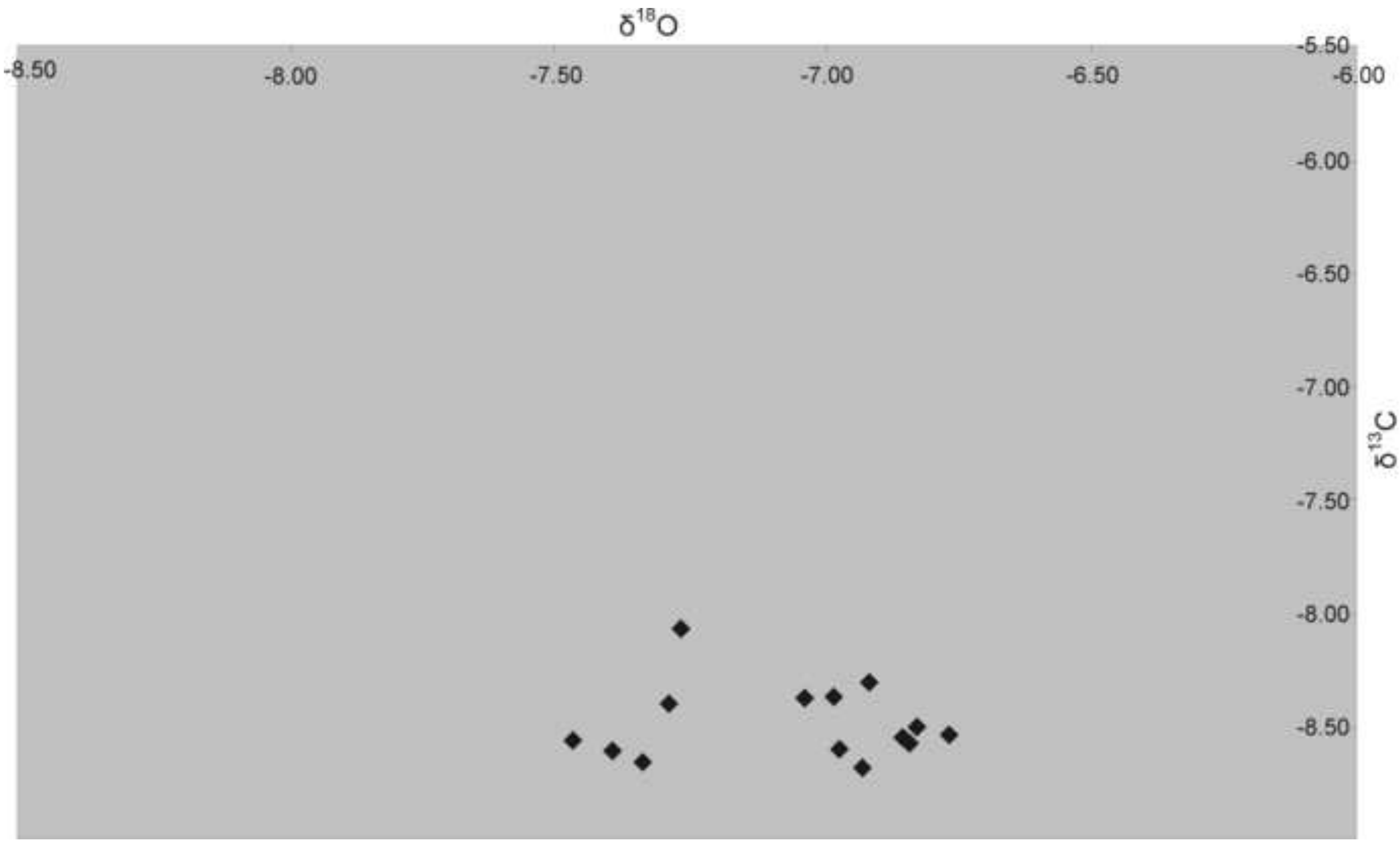

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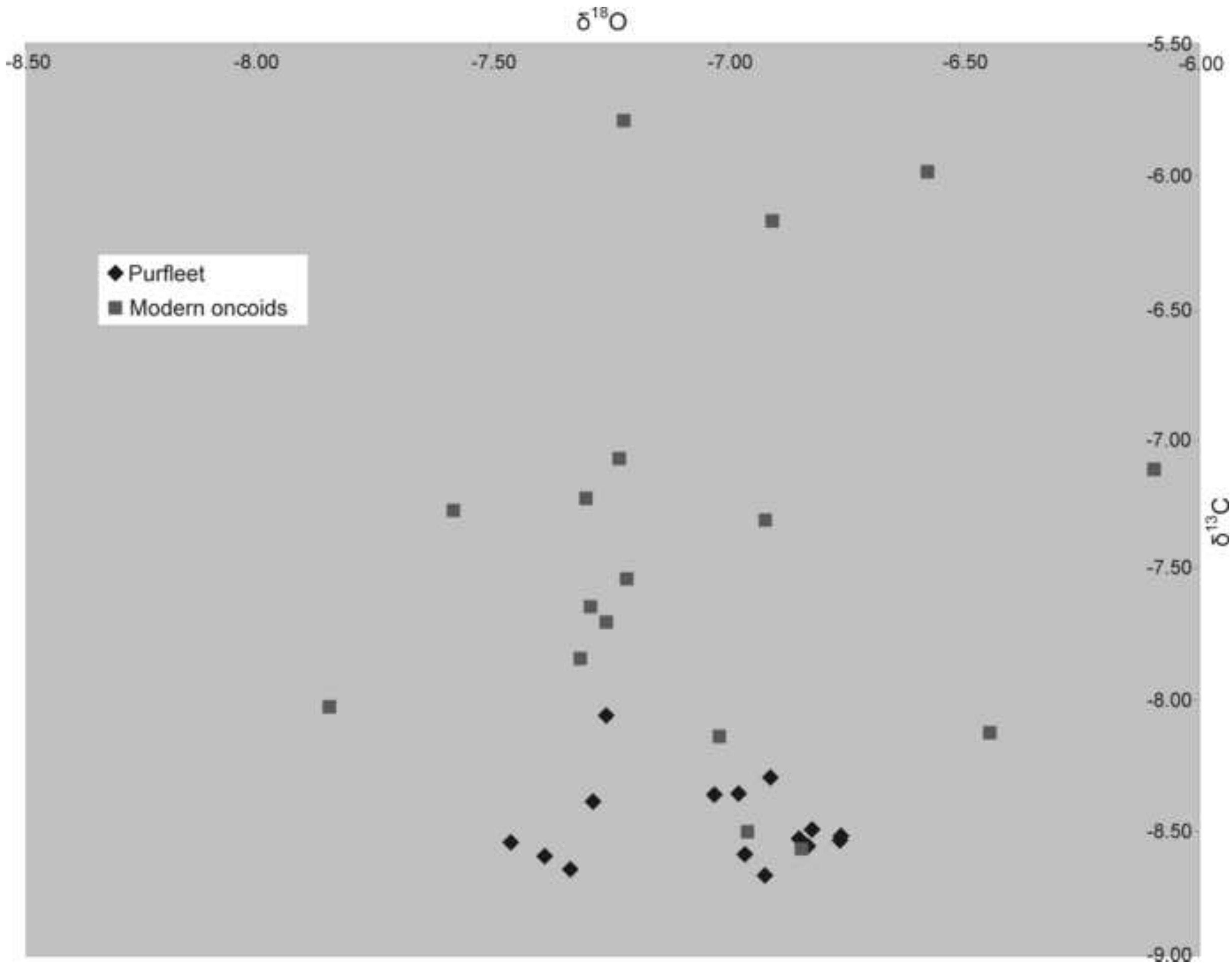

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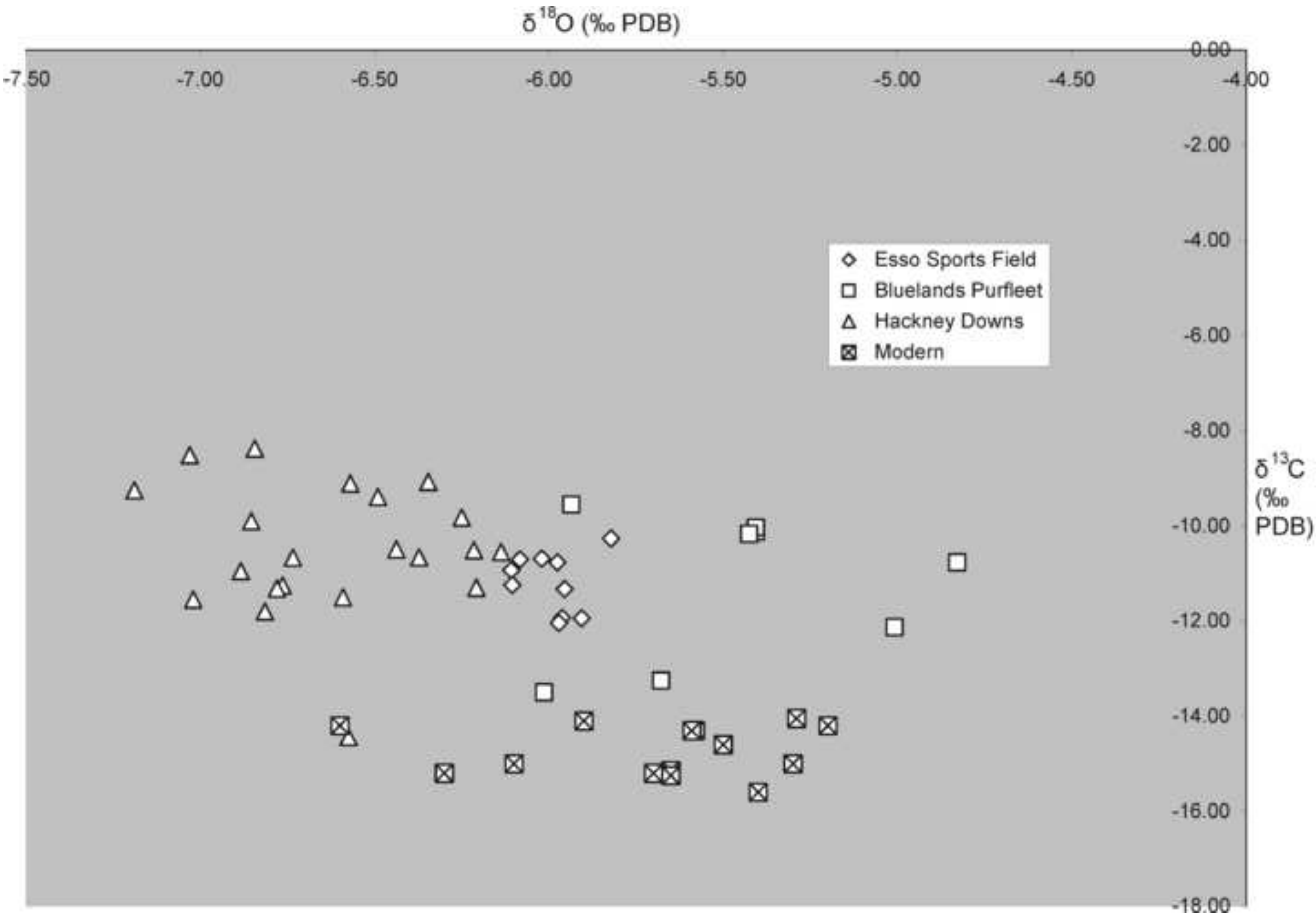

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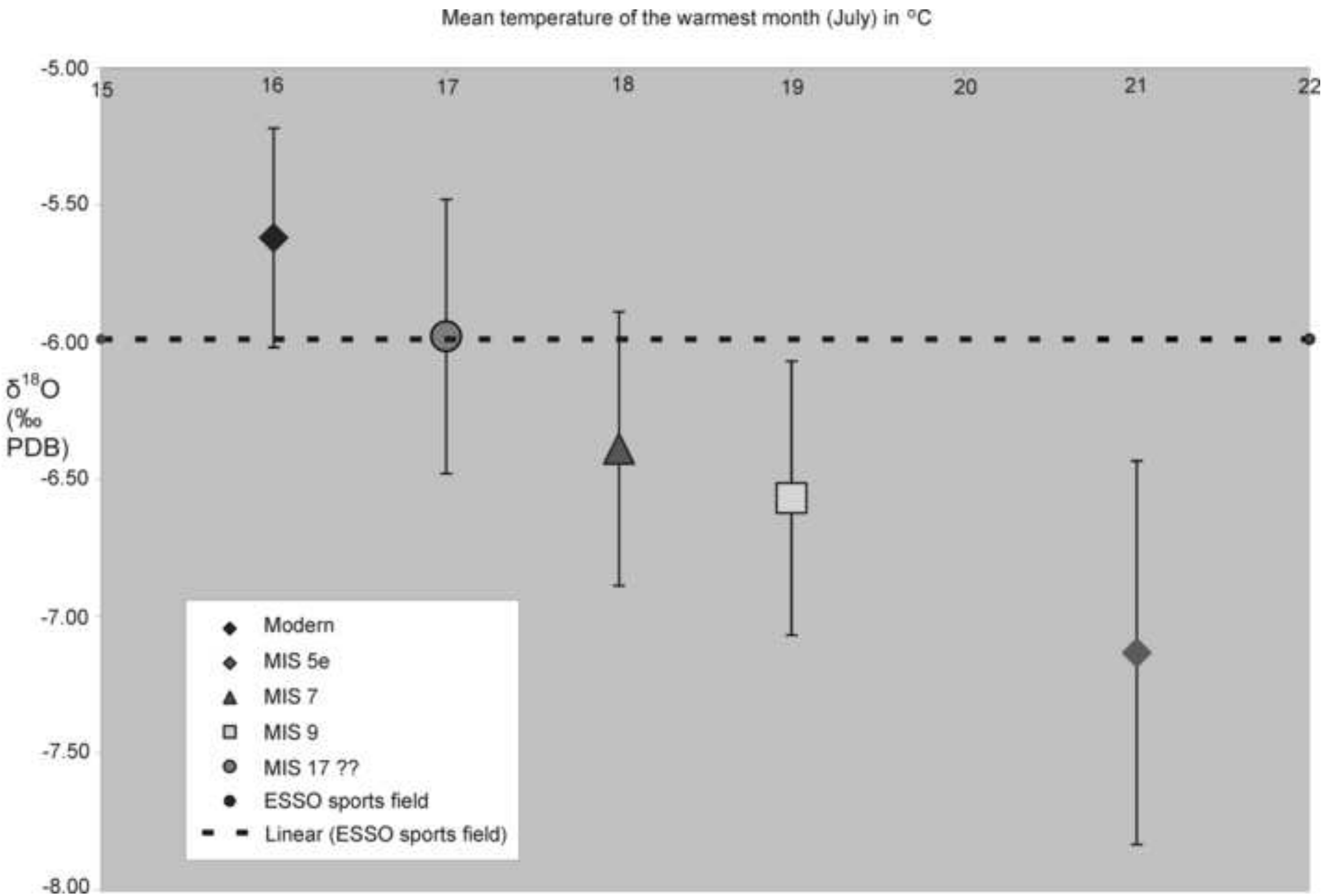

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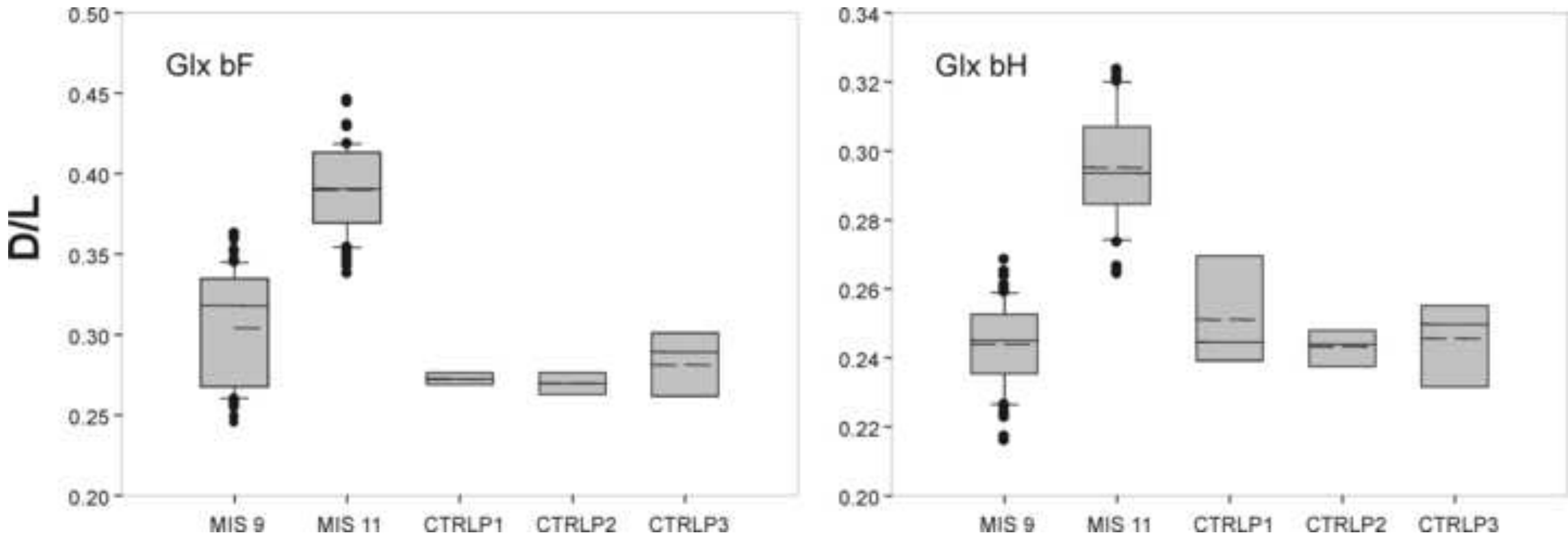

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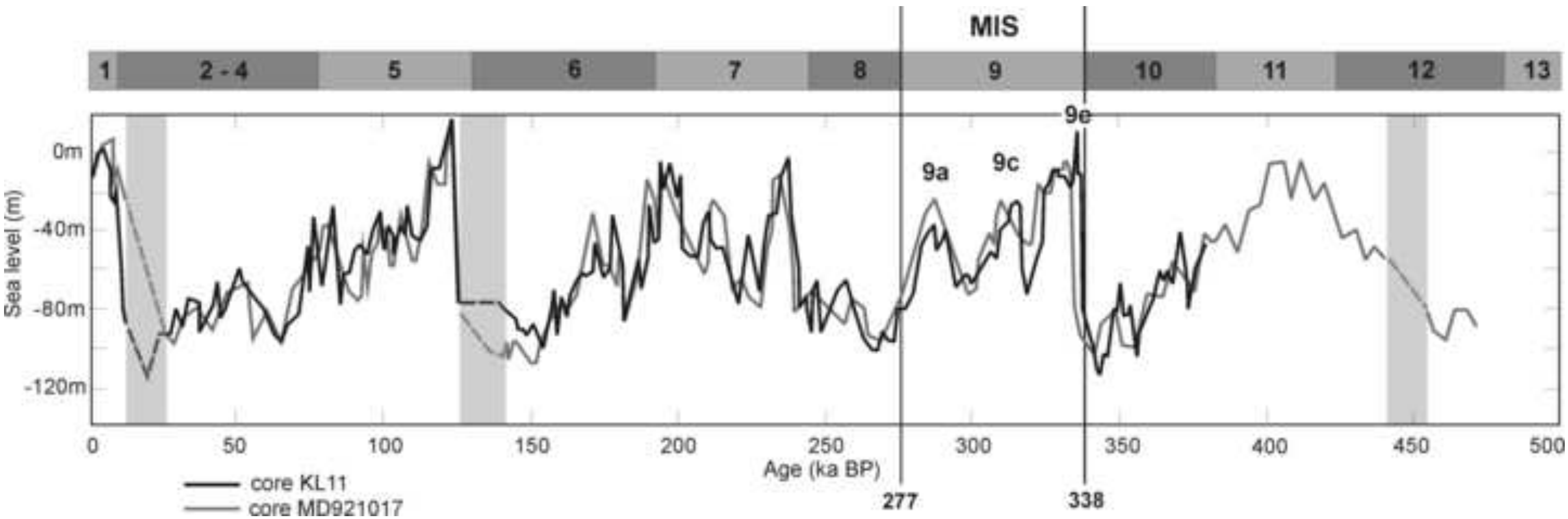

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