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Article

Mid-Late Quaternary Fluvial Archives near the Margin of the MIS 12 Glaciation in Southern East Anglia, UK: Amalgamation of Multi-Disciplinary and Citizen-Science Data Sources

Peter Allen [1], David R. Bain [2], David R. Bridgland [3,*], Paul Buisson [4], Jan-Pieter Buylaert [5], Rachel Bynoe [6], William H. George [7], B. Andrew Haggart [8], David J. Horne [9,10], Ellen-May Littlewood [11], Alan R. Lord [12], Anna C. March [9], Ian Mercer [13], Rosalind Mercer [13], Andrew S. Murray [14,15], Kirsty E. H. Penkman [16], Richard C. Preece [17], John Ratford [18], Danielle C. Schreve [19], Andrew J. R. Snelling [20], Kadri Sohar [21], John Whittaker [10], Mark J. White [22] and Tom S. White [23]

1 Independent Researcher, Waltham Cross, London EN8 9NB, UK
2 Independent Researcher, Thorpe le Soken, Essex CO 16 0HL, UK
3 Department of Geography, Durham University, Durham DH1 3LE, UK
4 Independent Researcher, Clacton-on-Sea, Essex CO15 5AR, UK
5 Department of Physics, Technical University of Denmark, DTU Risø Campus, DK-4000 Roskilde, Denmark
6 Department of Archaeology, University of Southampton, Southampton SO14 1BF, UK
7 Independent Researcher, Barking, London IG11 9SJ, UK
8 School of Science, The University of Greenwich at Medway, Chatham ME4 4TB, UK
9 School of Geography, Queen Mary University of London, London E1 4NS, UK
10 Department of Earth Sciences, Natural History Museum, London SW7 2BD, UK
11 Independent Researcher, Durham DH1 2JR, UK
12 Senckenberg Forschungsinstitut Frankfurt, D-60325 Frankfurt-am-Main, Germany
13 Independent Researcher, Chelmsford CM1 7DD, UK
14 Nordic Laboratory for Luminescence Dating, Department of Geoscience, Aarhus University, DK-8000 Aarhus, Denmark
15 DTU Physics, DTU Risø Campus, DK-4000 Roskilde, Denmark
16 Department of Chemistry, University of York, York YO10 5DD, UK
17 Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, UK
18 Independent Researcher, Clacton-on-Sea, Essex CO15 6NT, UK
19 Department of Geography, Royal Holloway University of London, Egham TW20 0EX, UK
20 Independent Researcher, Aldeburgh, Suffolk IP15 5JZ, UK
21 Department of Geology, University of Tartu, Ravila 14a, 50411 Tartu, Estonia
22 Department of Archaeology, Durham University, Durham DH1 3LE, UK
23 Department of Life Sciences, Natural History Museum, London SW7 2BD, UK
* Correspondence: d.r.bridgland@durham.ac.uk

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Abstract: This paper presents an updated geological reconstruction of the Quaternary evolution of the River Thames at its downstream extremities, close to the North Sea coast, based on new data from multi-disciplinary and citizen-science sources. In this area, the interaction of the Thames with the MIS 12 (Anglian) glaciation is an important part of the Quaternary archive. The Anglian ice sheet, which reached parts of north and east London, was responsible for diverting the Thames southwards into its present course, although the footprint of the maximum ice sheet(s) does not reach the North Sea coast south of Hollesley, Suffolk. Further south, the coastal zone hosts pre-Anglian and early Anglian river-terrace deposits of the pre-diversion Thames system, superimposed upon which are products of later post-Anglian rivers, of both Middle and Late Pleistocene age. On the peninsula between the Stour and Blackwater–Colne estuaries, the lowest and most recent terrace of the pre-diversion Thames includes evidence directly pertaining to the glacial disruption event, for which geochronological data are reported here for the first time. The first post-diversion terrace of the Thames also reaches this peninsula, the river having essentially re-joined its original valley before crossing the alignment of the modern coastline. This terrace passes beneath Clacton-on-Sea, where it includes the type locality of the Clactonian Palaeolithic Industry. The area of interest to this paper, in NE Essex and southern Suffolk, includes a number of interglacial and Palaeolithic sites, the data from which assist in constraining the chronostratigraphy of the sequence. In some cases, there has been uncertainty as to whether these sites represent pre-Anglian environments and hominin occupations, part of the palaeo-Thames sequence, or whether they are the product of later post-Anglian streams, formed after the Thames had migrated southwards. This paper compiles evidence from a wide range of recent sources, including developer-funded archaeological appraisal and citizen-science activities, to explore and update the evidence from sites at Ipswich, Upper Dovercourt and Thorpe-le-Soken, as well as a number of localities associated with the Clacton Channel Deposits (host to the type-Clactonian), amongst others. The resulting new data are placed within the wider context of the Quaternary fluvial archives in southern Britain, with a discussion of how disparate sources of information, including the work of citizen scientists, have contributed.

Keywords: fluvial archives; MIS 12 glaciation; River Thames; molluscs; Palaeolithic artefacts; ostracods; citizen science; luminescence dating; AAR dating

1. Introduction

In Britain, there is a strong consensus that the most extensive Quaternary glaciation occurred during the Anglian Stage and that this correlates with the marine oxygen isotope stage (MIS) 12 (e.g., [1–5]). It has also long been known that the Anglian ice sheets invaded the former valley of the River Thames, which was previously aligned north of London (Figures 1 and 2), effecting the glacial diversion of that river (Figure 2d) into its modern course through the capital city [6–9]. Although it impinges on the northern and eastern suburbs of London, the Anglian ice limit does not reach the North Sea coast south of Hollesley, in the County of Suffolk; south from there is a widening unglaciated coastal zone dominated by pre-Anglian and early Anglian Kesgrave Group river-terrace deposits of the pre-diversion Thames system (Figure 1), mostly gravel but including the localized preservation of interglacial deposits, notably at Ardleigh, Little Oakley, Wivenhoe and Walton-on-the-Naze (Figures 3 and 4) [9–11]. Superimposed upon the pre-Anglian terrace staircase are the products of later post-Anglian rivers that now drain into the North Sea, some of them (those furthest south, at least) potentially tributaries of the offshore Thames system during the low-sea-level phases of the late Middle and Late Pleistocene. In bringing together recent research on Quaternary fluvial archives in the key area of northern Essex and southern Suffolk that straddles the MIS 12 glacial limit (Figure 1), this paper provides an updated understanding of drainage evolution before and after the diversion of the Thames. New data presented here include the dating, palaeontology and artefact content of the fluvial sediments, based on disparate sources that include recently published material, some of it not easily accessed, planning-based archaeological assessment (some of which is available from grey literature) and work, especially monitoring and collecting, by citizen-scientists. In particular, the paper highlights the value of integrating the work of professional and citizen scientists.

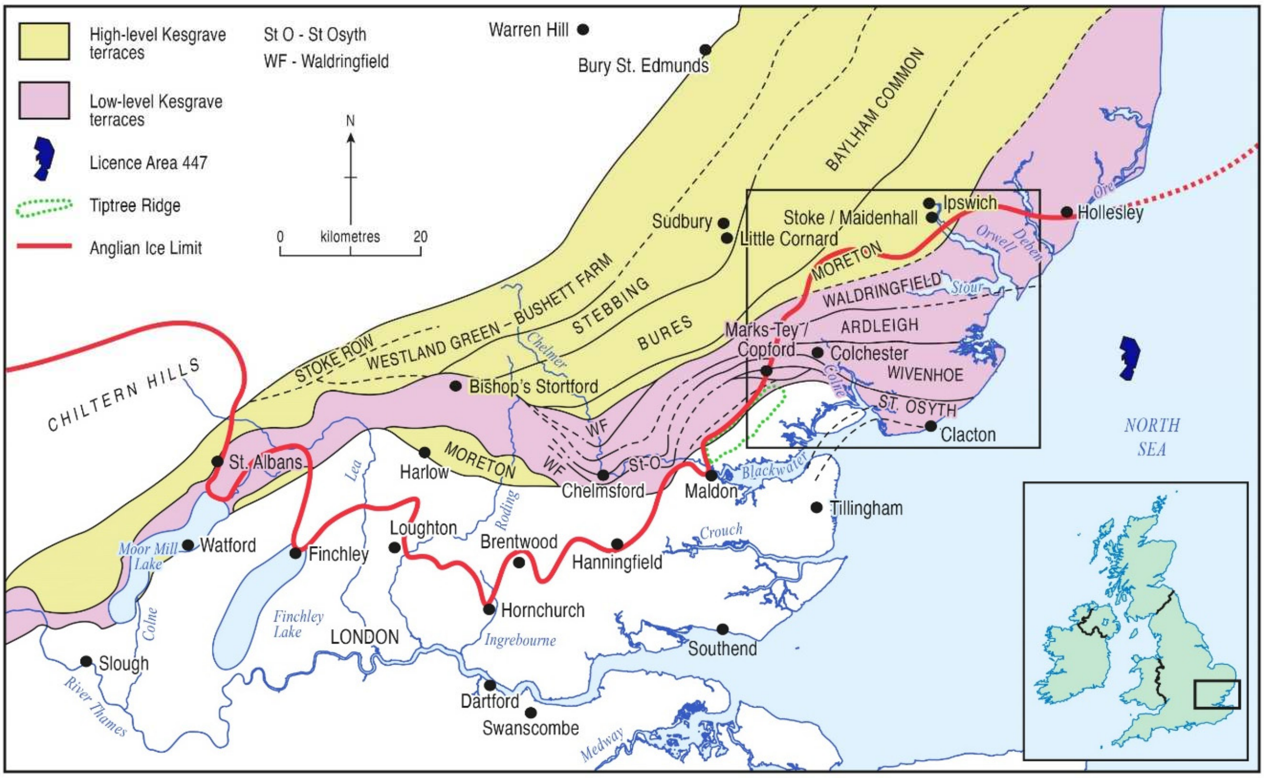


Figure 1. Location of the study area (as depicted in Figure 3—see box). Pre-diversion Thames fluvial archives are illustrated (modified from [12,13]). Also shown are Licence area 447 (see text), the Anglian (MIS 12) glacial limit and palaeolakes formed at its margin in the London area (see also Figure 2) and locations mentioned in the text that do not appear in other figures.

The bedrock beneath the dominant superficial Quaternary deposits in this unglaciated coastal zone comprises the largely unconsolidated Eocene strata of the Harwich and London Clay formations, together forming the Thames Group [14]. The British Geological Survey (BGS) identifies as bedrock the Thames Group as well as the Pliocene–Pleistocene Coralline Crag, Red Crag and Norwich Crag formations [15]. The area lies at the western fringe of the subsiding Cenozoic marine North Sea basin, in which deposits that include the above-mentioned marginal crags have accumulated, interbedded with the sediments of the Rhine–Thames delta [16–18], on the western flank of the Eridanos (Baltic River) delta system [19]. The surviving spreads of the Pliocene–Pleistocene Red Crag, highly fossiliferous when unweathered, are thin and widely separated in northernmost Essex, becoming considerably more substantial further north, where the older Coralline Crag and younger Norwich Crag also occur (Figure 3).

North of the study area, the Kesgrave Thames-terrace sequence can be traced through Suffolk and into Norfolk (Figure 1) [12,13,20–22]. From NW to SE, these pre-diversion Thames deposits become progressively younger in age as a terrace staircase is descended (Figure 5). The oldest of these terrace gravels, belonging to the High-level Kesgrave Subgroup, follow a former course inland of the east coast and extending towards north Norfolk [21]. Northwards from the Ipswich area, this early Thames route is consistently westward of the later, early Middle Pleistocene course of the Low-level Kesgrave Thames (Figures 1–3). In north Suffolk and Norfolk, however, there is evidence that a substantial pre-Anglian river flowed into East Anglia from the west, carrying material from the Midlands [21,23]. Now recognized as the former River Bytham [24,25], this cut through the pre-existing High-level Kesgrave gravels and was confluent with the Thames, eventually replacing it as the main agent of drainage in north Suffolk (Figure 2a,b) [26]. Subsequently, gravels in northern East Anglia, formerly classified as Kesgrave, were deemed to be part of a newly defined shallow marine Wroxham Crag (Figure 2a,b) [27–29], although this has not been universally accepted [30] (cf. [23]). Indeed, it is plausible that both fluvial and shallow-marine Lower Pleistocene deposits could be represented in this area, reflecting the sea-level fluctuation that would have occurred during climatic oscillations, even those of more modest amplitude that preceded the Mid-Pleistocene Revolution.

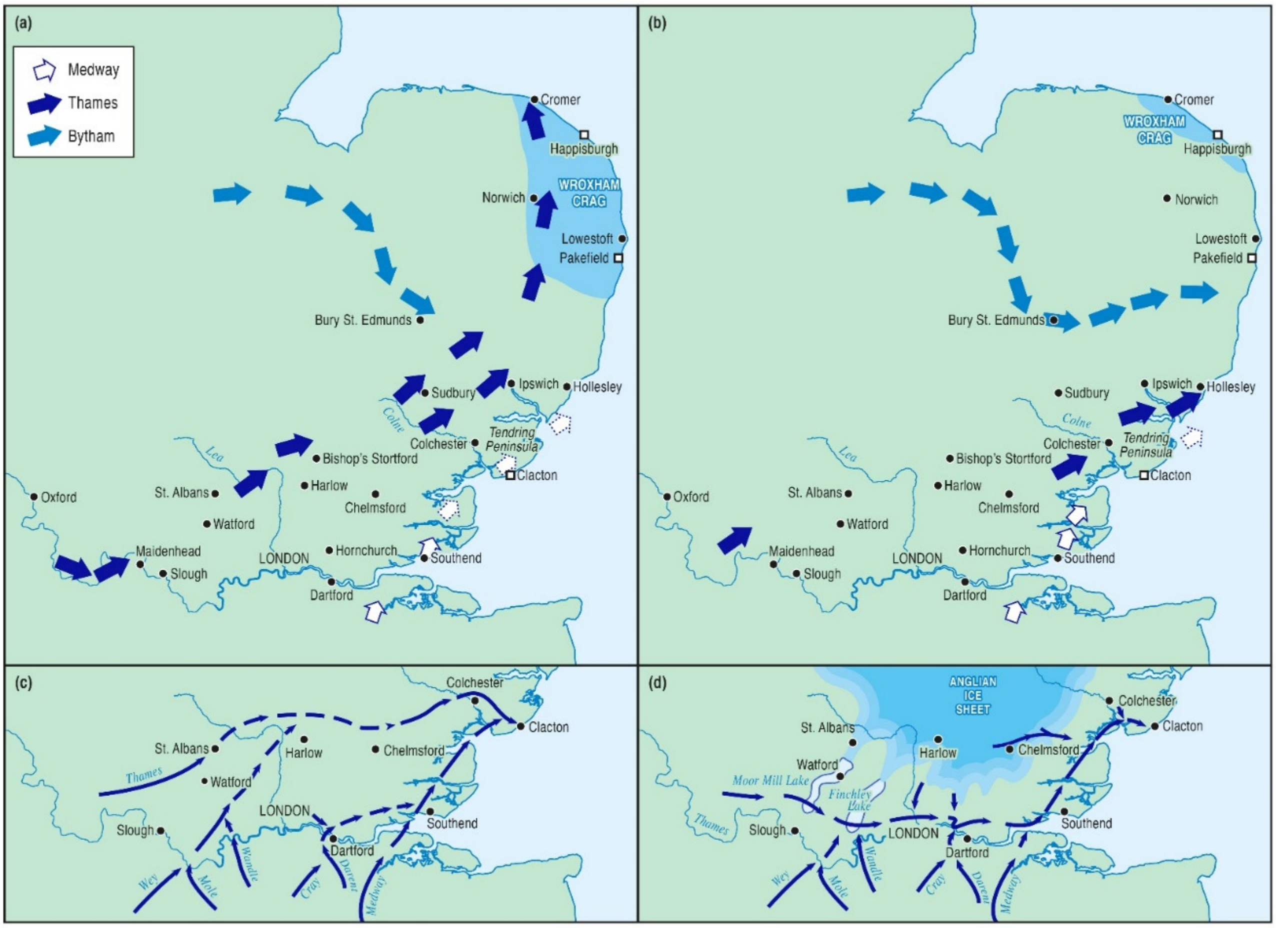


Figure 2. Evolution of Thames drainage (modified from [31]), showing the location of key sites. (**a**)—Early Pleistocene (Westland Green Gravel); (**b**)—early Middle Pleistocene (Waldringfield Gravel); (**c**)—immediately prior to the arrival of Anglian (MIS 12) ice; (**d**)—The Anglian glaciation and the initial diverted course.

Southwards from the area under consideration, the limit of advancing Anglian ice was increasingly controlled by the Chalk escarpment, which rises in height to reach over 200 m O.D. in the Chiltern Hills, NW of London (Figure 1), although it is only 50 to 20 m O.D. in Suffolk. The ice penetrated through the Chilterns in four separate pulses, by way of gaps and pre-existing valleys, reaching the northern outskirts of London at Moor Mill (Thames) and Finchley (Mole–Wey tributary), blocking the Thames and causing its diversion into its modern valley (Figure 2) [8,9,32,33]. To the east, the ice crossed the more subdued Chalk outcrop, as evidenced by ice-thrusted chalk rafts in the Royston area [34], but was constrained by the higher ground formed on the Palaeogene strata in Essex, probably the southern flank of the Thames palaeo-valley, although, again, it penetrated into supposed tributary valleys to Loughton (palaeo-Roding), Hornchurch (palaeo-Ingrebourne), Hanningfield (Chelmer gap) and Maldon (palaeo-Blackwater), as shown in Figure 1.

Figure 3. Quaternary deposits of the study area, updated from [31] and showing the sites from which new data have been obtained. The location of this figure is indicated on Figure 1.

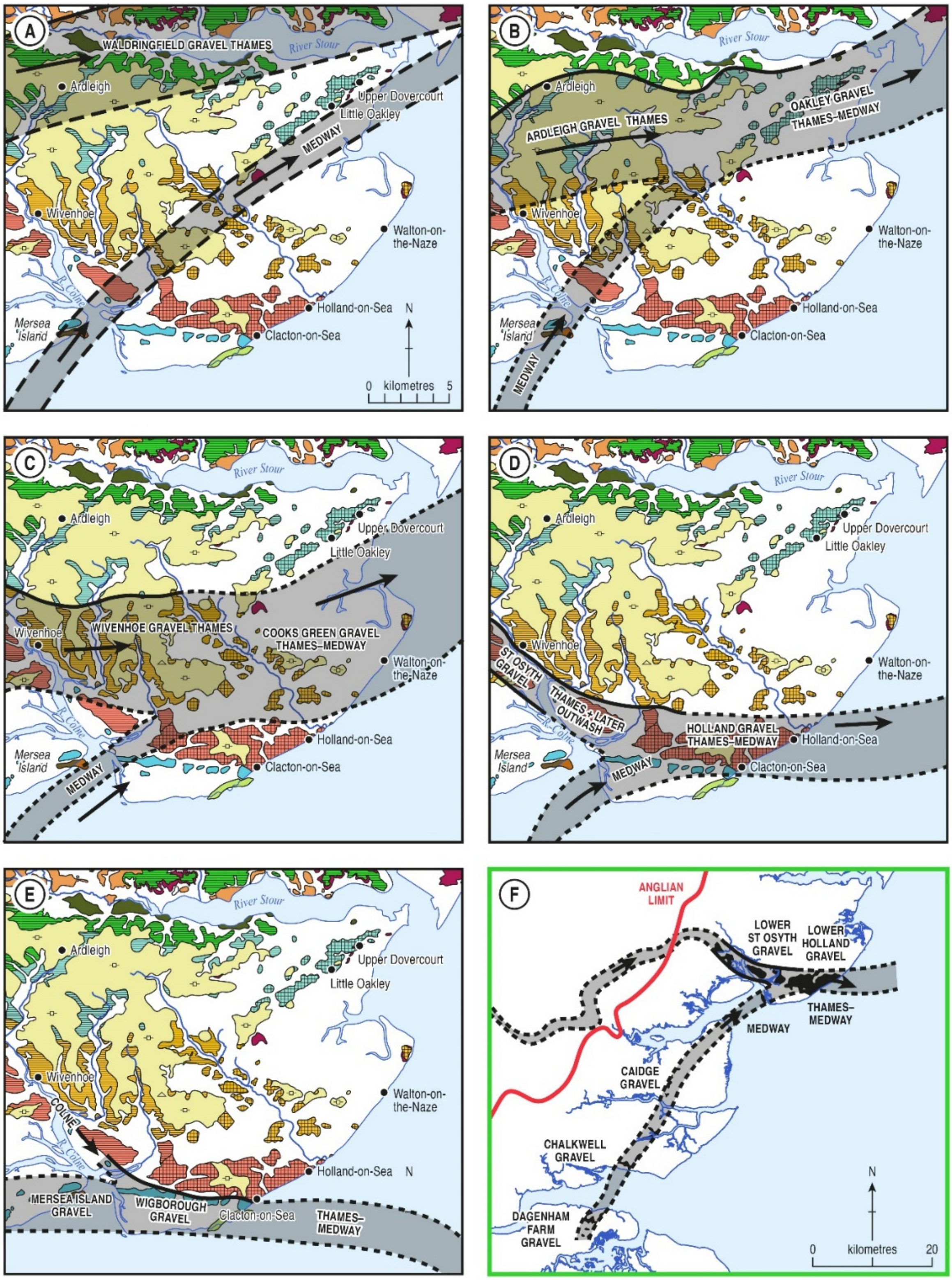


Figure 4. Former courses of the Thames–Medway system across the study area, derived from the Tendring Geodiversity Audit of Essex County Council [35] (original sources [9,31]). (**A**)—Waldringfield Gravel; (**B**)—Adleigh–Oakley Gravel; (**C**)—Wivenhoe Gravel; (**D**). St Osyth–Holland Gravel; (**E**)—the first post-diversion course; (**F**)—the wider St Osyth–Holland Gravel course, showing the relation to the ice limit (Table 1).

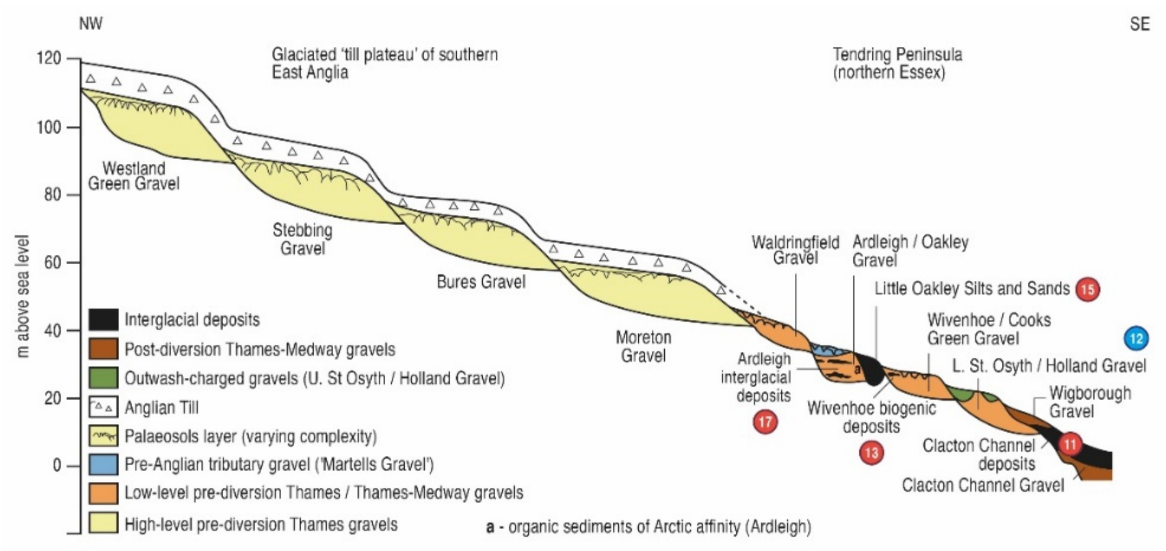


Figure 5. Idealized transverse section through the pre-diversion terraces of the River Thames in southern East Anglia, after [36]. Note the greater complexity of palaeosols capping progressively higher terraces [37]. Interglacial deposits interbedded with the cold-climate terrace gravels on the Tendring Peninsula are indicated. Proposed MIS correlations are indicated in roundels, red for interglacials and blue for glacials.

Table 1. The Thames terrace sequence in Essex and Suffolk [9,31,38].

Group	Formation		Proposed MIS
	Essex	**Suffolk**	
Low-level East Essex Gravel	Wigborough		1–11–10
[Part of Lowestoft Formation?] [1]	Upper St Osyth [1]		12
KESGRAVE GROUP Low-level Kesgrave Subgroup	Lower St Osyth Wivenhoe Ardleigh Waldringfield	(Older formations offshore) Waldringfield	12 14–13–12 18–14 >18
KESGRAVE GROUP High-level Kesgrave Subgroup	Moreton Bures Stebbing Bushett Farm	Moreton Baylham Common	Lower Pleistocene

[1] As a glacial outwash deposit this should perhaps be assigned to the Lowestoft Formation.

The ice in central Essex was probably thin (~50 m), as it failed to surmount the SE flank of the Thames valley, now represented in part by the Tiptree Ridge (Figure 1). The ice limit in Suffolk is poorly determined, being derived from the most south-easterly outliers of till and occurrences of over-deepened valleys, such as the Orwell [39–44]. A large fluvio-glacial outwash fan was developed at Ipswich, fed by the emergent Gipping (Figure 3) [45]. Another such fan has been envisaged in the Colchester area, fed by the Essex Colne [46], although the evidence presented is unconvincing and the sediments attributed to this feature were previously interpreted as Kesgrave sands and gravels, based on the recognition of the pre-Anglian Valley Farm palaeosol developed on these deposits [47] (refs. [48,49] (see Figure 5). The Colne is, nonetheless, regarded as a river that was initiated as a glacial outwash stream, since it is partly formed along the final course of the pre-diversion (Kesgrave) Thames, marked by the Lower St Osyth Gravel, with overlying distal outwash recognized in the form of the Upper St Osyth Gravel (see Table 1).

Glacial lakes were common at the Anglian ice margin, famously at Moor Mill, near Watford and Finchley, associated with the diversion of the Thames (Figure 2) [8,9]. Another important glacial lake formed in what may have been a subglacially over-deepened section of the pre-diversion Thames system lying within the Anglian ice margin (probably in a north-bank tributary) at Marks Tey and Copford. The infill of this lake continued through the subsequent MIS 11 interval and possibly longer. The Marks Tey basin-fill begins with lacustrine deposits of the Anglian late-glacial and the Hoxnian interglacial parastratotype (MIS 11c) and then continues with a substantial lacustrine sequence (with minor fluvial components), providing an unparalleled record of the post-Hoxnian climate complexity that includes cold and warm intervals variously attributed to MIS 11b, MIS11a or to the 'early glacial' of MIS 10 [50–55].

In Suffolk, the accommodation space associated with glacial processes or pre-glacial drainage was filled, mostly during recession and deglaciation, with outwash sands and gravels, diamicton and finer-grained lacustrine silts and sands. A notable example, to be featured below, is the site excavated by Nina Layard in the early 20th century at Foxhall Road, Ipswich, where infilling continued, as at Marks Tey, throughout the subsequent MIS 11c interglacial [56–58]. Marks Tey has provided the biostratigraphical (pollen) constraint for the transition between the Anglian and Hoxnian stages (MIS 12 to MIS 11c) [50], confirmed in Hertfordshire [59–61] and Suffolk [42]. The MIS 11c assignment of the Hoxnian is now confirmed at Marks Tey by tephrochronology [62]. Occurrences of the ostracod *Ilyocypris quinculminata* support an MIS 11 age for the post-Hoxnian sequence at Marks Tey.

2. Geological Setting: The Tendring Peninsula and Southern Suffolk (Baseline Knowledge)

On the Tendring peninsula, between the Stour and Blackwater–Colne estuaries, there are four terraces of the pre-diversion Thames, formed by the Waldringfield, Ardleigh, Wivenhoe and St Osyth gravels, part of the Low-level Kesgrave Subgroup (Figure 3) [9,31]. The lower three of these pass eastwards (downstream) into equivalent Thames–Medway gravels, reflecting a confluence with the pre-Anglian Medway and marked by an increase in the proportion of clast lithologies derived from south of the North Downs, mainly Lower Greensand chert. These are, in descending order, the Oakley, Cooks Green and Holland gravels (Figure 3) [9,31]. The Waldringfield Gravel appears to have no Thames–Medway equivalent preserved onshore, there being a relatively insignificant southern component in even its furthest downstream extent. This, the oldest Low-level Kesgrave Thames formation, has been attributed to the earliest Cromerian Complex (latest Matuyama chron), on the basis of uplift modelling [63], there being no biostratigraphical evidence from this division of the Low-level Kesgrave Subgroup. Although there are younger deposits, associated with the River Stour and its estuary, inset into its northern edge (Figure 3), the northernmost fringe of the Tendring plateau is on Waldringfield Gravel, which is the only division within the Low-level Kesgrave terrace staircase to extend north of the Stour. There have been no quarry exposures in this division south of the Stour in recent decades, but it was sampled by manual trial-pit excavation at Mistley Heath (Figure 3), providing samples for clast-lithological analysis (see Supplementary Materials Tables, Table S1).

The next highest division of the Low-level Kesgrave terrace staircase, the Ardleigh Gravel, incorporates, at its type locality, temperate-climate sediments that have been attributed to a Cromerian Complex interglacial, probably in the range of MIS 19–15 [9,31,63,64]. Its downstream Thames–Medway equivalent, the Oakley Formation, also incorporates interglacial sediments, in the form of the Little Oakley channel deposits, of comparable but not necessarily identical age [9,11,65]. These deposits contain ostracod and vertebrate fossils indicative of an interglacial climate, with summers at least as warm as present-day [66,67] (D.J. Horne & J. Whittaker, unpublished data).

Temperate-climate sediments have also been observed in both the Thames and Thames–Medway components of the next terrace, formed by the Wivenhoe–Cooks Green Gravel. At Wivenhoe, organic sediments of warm-climate affinity have been encountered interbedded with cold-climate (periglacial) gravels of Low-level Kesgrave type [9,10,68]. The organic sediments comprise silty clay containing pollen, plant macrofossils and insect remains. Palynological study [10] revealed *Betula*, *Pinus*, *Picea* and *Alnus* with subordinate *Abies*, *Ulmus*, *Quercus*, *Carpinus*, *Corylus* and *Salix*. Although clearly cool temperate in affinity, this assemblage is not stratigraphically diagnostic, and neither were the plant macrofossils (M.H. Field, in [9]). Two small flint flakes from the organic sediment represent possible artefacts, at the time a controversial discovery [10], but unsurprising in light of the discovery of artefact assemblages in significantly older sediments, further north on the coast of East Anglia [69–71].

The Wivenhoe Formation passes eastwards into its Thames–Medway equivalent, the Cooks Green Formation. Sediments capping the cliff at Walton-on-the-Naze, overlying the Waltonian Red Crag, are attributed to the Cooks Green Formation; they include gravels and silts, some of the finer-grained divisions yielding interglacial pollen, including *Quercus* and 'Type X', the latter leading to an original attribution to the Hoxnian Stage [72], although it is now regarded as important evidence for the pre-Anglian occurrence of the 'Type X' palynomorph [73,74]. A further occurrence of probable late Cromerian Complex interglacial deposits came from sections created in the Cooks Green Gravel outcrop at Weeley Heath, during the construction of the Weeley bypass in 1993–1994. These temporary exposures revealed mainly fine-grained deposits, including organic sediments, some containing wood fragments [75,76]. Lower and upper gravel facies were also present, respectively below and above the organic sediments. Unfortunately, the latter have never been studied in detail, although in character they resemble the deposits at Wivenhoe, upstream within the same terrace of the pre-diversion Thames.

The gravels at Weeley Heath were studied using clast-lithological analysis (see Supplementary Materials Tables, Table S1) and found to include examples that could be attributed to the pre-diversion Thames–Medway, as fits with the occurrence within the Cooks Green outcrop: Samples 1 and 2B, albeit both with unusually large components of southern indicators, suggesting strong Medway affinities. Sample 2A contained low proportions of southern, potentially Medway-derived material, however, and has been interpreted as representing the bedload of the Thames upstream from its confluence with the Medway. In contrast, sample 3 was entirely lacking in Thames indicator clasts, suggesting that it represented Medway bedload in a separate channel upstream of the joining of the two rivers, presumably within a wider floodplain in the area of their confluence. Both samples contained high proportions of locally derived non-durable material from the London Clay (as well as fragments of wood and other plant fossils), thus yielding lower counts of the key clast types from which such inferences can be drawn. The clear implication, nonetheless, is that the palaeo-confluence between the Thames and Medway was situated very close to the Weeley Heath locality at the time represented. An unusually high representation of non-durables has been observed to occur relatively frequently in gravels representing interglacial episodes, rather than in cold-climate-gravels representing high-energy periglacial braid-plains. Examples of the former include Swanscombe [9] and Purfleet [77], in the Lower Thames, in which bedrock chalk as well as material derived from the London Clay occurs.

The lowest pre-diversion Thames and Thames–Medway terrace on the Tendring peninsula, formed by the St Osyth–Holland Gravel, records the glacial disruption of the river system in that it comprises standard fluvial gravels, essentially similar to those forming the higher terraces, overlain by sand and fine-grained gravels that represent the period when the drainage was impeded by ice sheets covering central Essex (Table 1). Upstream of the Thames–Medway palaeo-confluence, the fine-grained Upper St Osyth Gravel contains an unusually large proportion of clast types associated with glacial outwash from the eastern British ice (See Supplementary Table S1), notably *Rhaxella* chert [78,79], as well as a much lower ratio of rounded Palaeogene flint pebbles to flints from other sources (nodular flint of recent extraction from the Chalk and broken/weathered flint reworked from earlier gravels). This latter characteristic can be attributed a derivation from the north, where Palaeogene flint is rarer, rather than from the south, where such secondary flint pebbles are readily provenanced from the infill of the London Basin and generally dominate early Quaternary gravels [9,31]. Further east, the gravels change markedly and have a large Greensand chert component, showing that they are dominated by material of Medway origin, although a small proportion of glacial indicator clasts are still present. This 'Upper Holland Gravel' has been interpreted as representing the unglaciated River Medway downstream of its confluence, near St Osyth, with a distal outwash stream draining the Anglian ice sheet by way of the erstwhile Thames channel [9,10,31]. Cliff stabilization work in autumn 2018 provided temporary sections in the Holland Gravel that were recorded and sampled for clast analysis and luminescence dating, throwing further light on this sequence. Results appear below.

Along the southern edge of the Tendring peninsula, the archive of drainage disruption is completed by a final, lowest terrace that represents the immediate post-diversion river system. At Brightlingsea are gravels that record the early post-Anglian River Colne, with a downstream transition into the Wigborough Formation, the latter incorporating the well-known and widely researched Clacton Channel Deposits (see below). Thus, the first post-diversion route of the Thames brought the river to the southern fringe of the area under consideration, where it essentially re-joined its original valley. The glacial diversion was therefore a somewhat localized feature within the drainage system (Figure 2). There were, however, profound changes in the area further downstream, with a more fundamental glacial diversion of the Rhine–Thames system from the North Sea delta that had been forming since pre-Quaternary times [16,17,80] (see above), via a newly excavated breach in the Chalk of the North Downs and northern France, into the English Channel [16,81,82].

3. Materials and Methods

The reconstruction of the drainage evolution in the study region has involved the use of numerous multi-disciplinary lines of evidence, including the basic mapping of sediments and landforms, sedimentology, palaeontology and geochronological techniques (e.g., [9–13,15,83–85]. Lower–Middle Palaeolithic archaeology constitutes widespread and important further evidence that is akin to palaeontology, in that lithic artefacts occur as components of the sedimentary archive and have chronological and environmental significance [86–88].

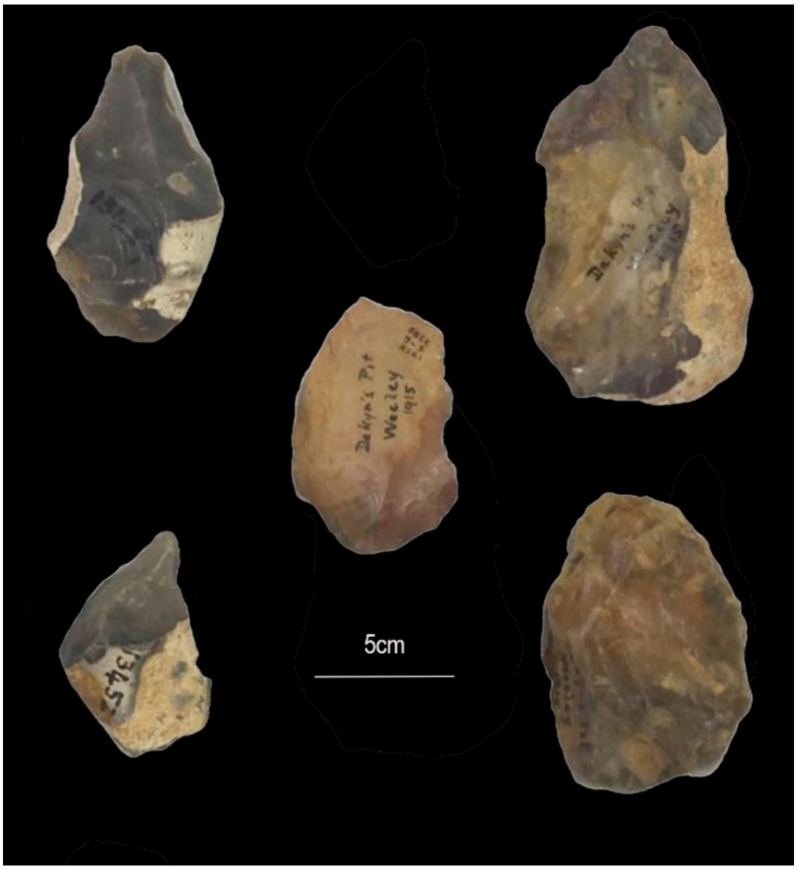
A single method statement is inappropriate for this paper, since it is a compendium of findings from a range of projects and data sources, each with its own methodology, as will be described in the following sections. In general, the new data reported here have been obtained from the opportunistic monitoring of, and collection from, temporary sections or periodically refreshed exposures of key sediments, such as those that occur in marine cliffs and on foreshores. Sometimes, the collected material is allochthonous, either eroded from such sections and found loose nearby, or introduced from a source deposit elsewhere, as in the case of beach recharge, an example of which has provided important new information about the fluvial archives offshore from the study area. New temporary sections have been created at some of the sites reported, either for the purpose of scientific investigation (including archaeological assessment) or for other reasons, the scientific investigations being opportunistic. Data, including fossils, have also been obtained from boreholes in advance of development. In addition, the work reported includes the reappraisal of existing collections, such as the Palaeolithic artefact assemblages, in the light of recent advances in knowledge and understanding.

Data reported from the various newly researched sites enable the enhancement and, occasionally, the modification of the established version of stratigraphy and events in the area separating the glaciated plateau of southern East Anglia from the North Sea. The reporting of these new data will be treated chronologically, in terms of Quaternary history, in the following sections. In addition to the pre-diversion and early post-diversion Thames and Thames–Medway sites described in Section 2, which have been researched previously, there are interglacial and Palaeolithic sites associated with local rivers and thus representative of the post-Anglian evolution of the area, after the Thames had migrated further south. Much of the new data presented here concern this part of the record. In addition, there are equivocal fluvial sites that might represent the post-Anglian drainage evolution or part of the pre-diversion Thames archive.

4. New Data: Pre-Anglian—Anglian

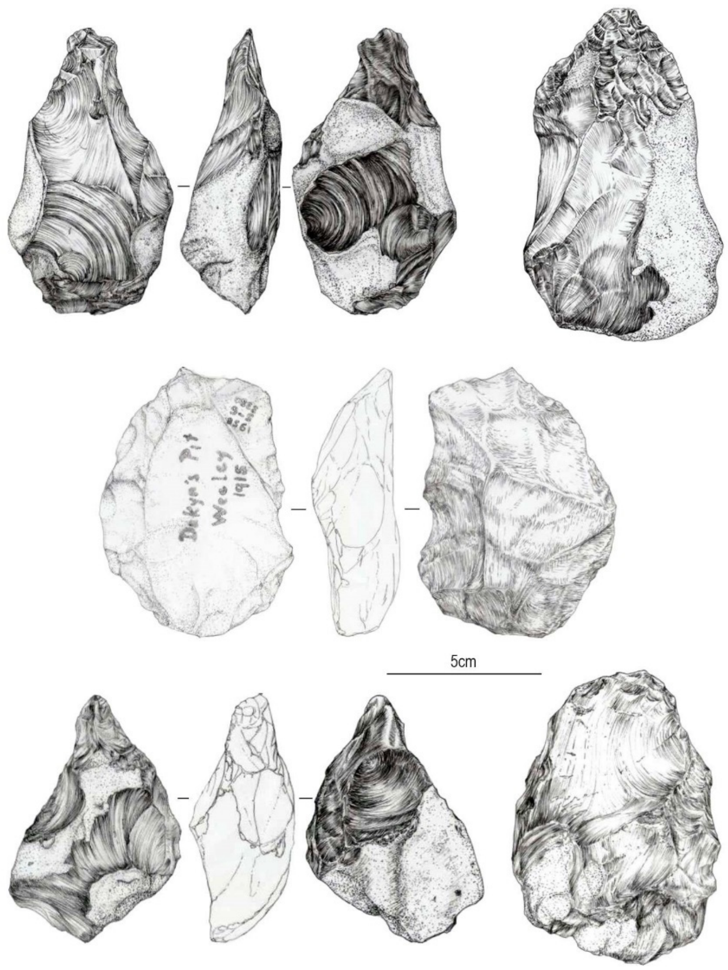
4.1. Daking's Pit (Thorpe-le-Soken)

Daking's Pit, located on the left bank of the Holland Brook, has been variously referred to in the literature as 'Daykin's Pit', 'Weeley' and 'Thorpe-le-Soken' (referencing both the neighbouring village and wider parish, respectively). Explorations of the site [89–91] and subsequent mentions [9,11] produced archaeological and lithological observations, with S.H. Warren [89] having amassed a small collection of hand-axes from the site. John Wymer's reclassification and cataloguing of the archaeological assemblage (flakes, cores, and hand-axes: Figure 6) [91], in accordance with his 1968 scheme [92], placed them within the broad mid-Acheulian. His description and interpretation of the site represent a time when the main gravels of the Tendring peninsula were regarded by many, including the Geological Survey, as glacial in origin, although others [49,90] considered them to be fluviatile. For most of Wymer's career, it was received wisdom that the occurrence of Palaeolithic artefacts in British Pleistocene deposits was restricted to the post-Anglian. This would have influenced his interpretation of the gravels at Daking's Pit as post-Anglian products of the local stream, the Holland Brook, which drains eastwards across the Tendring peninsula (Figure 3). The envisaged Holland Brook deposits would have been inset into, and largely derived from, the local Low-level Kesgrave gravels, which hereabouts belong to the Cooks Green Formation. Such post-Anglian gravels would therefore be difficult to distinguish from the Kesgrave deposits.



(**A**)

Figure 6. *Cont.*



(**B**)

Figure 6. Artefacts from Daking's Pit, Warren Collection, British Museum. (**A**) Photographs and (**B**) drawings (next page) by Ellen-May Littlewood.

The presence of *Rhaxella* chert in one of the two gravel analyses from the site (see Supplementary Materials Tables, Table S1) [11] raises the possibility of an Anglian or post-Anglian interpretation, given that this lithology, derived from the Jurassic of North Yorkshire, is an important glacial indicator and is generally absent from the Kesgrave Group [9,79]. *Rhaxella* chert is, however, a prominent exotic component of the Red Crag, remnants of which occur above the London Clay in parts of the Tendring Peninsula (see above, Figure 3), thus representing a potential source of such material in the pre-diversion Thames gravels in the easternmost part of the area.

The archaeological assemblage held at the British Museum was reassessed [93] with the aim of reclassifying it in accordance with Roe's hand-axe groups [94,95] and applying the chronostratigraphical correlations now suggested for these [86,87]. Only seven hand-axes were present, but all were crude and unrefined types consistent with an attribution to Roe's Group V (Figures 6 and 7), indicating that the dominant archaeology at the site could date from the pre-Anglian. Comparison with other sites in the wider region indicates a similarity to the rolled assemblage from Warren Hill, Mildenhall, attributed to MIS 15–13 [86,87,96,97]. However, the generally abraded condition of the Daking's Pit artefacts raises the possibility of later reworking during or after the Anglian; thus, a definitive pre-Anglian age for the gravel at the site cannot be claimed on this basis. Nonetheless, the post-Anglian interpretation favoured by Wymer [91] can no longer be considered unequivocal, and a pre-Anglian age is perhaps more likely.

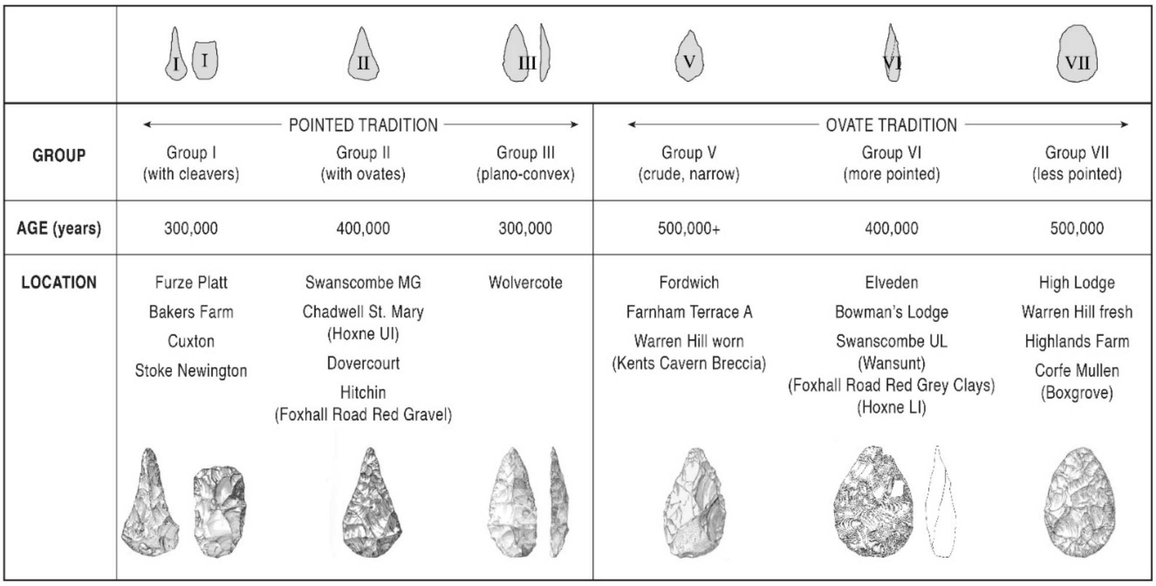


Figure 7. Derek Roe's (1968) hand-axe groups [94], with later additions in parentheses. Roe's Group IV, to which he allocated material transitional between the ovate and pointed traditions, is excluded, as it contains mixed and seemingly unreliable assemblages (reproduced from [95]).

4.2. Verification of the Chronostratigraphical Position of the Anglian Glaciation within the Thames Terrace Archive beyond the Ice Limit

A temporary section at Holland-on-Sea, made available as part of a cliff-stabilization program (Figure 8), enabled a new study of the sequence that is thought to mark the short-lived cessation of Thames drainage into its lower valley, coincident with the glacial blockage of the river in Hertfordshire (see Figure 2d). This sequence is represented in a site of special scientific interest (SSSI), some 1.4 km NE of the temporary section [9,10]. The sequence at both localities is similar, with coarser-grained Lower Holland Gravel, representative of the Kesgrave Thames–Medway, overlain by the sand-dominated Upper Holland Gravel. The fine-grained gravel beds making up the latter are of predominantly Medway composition, with large proportions of Lower Greensand chert. In the new section, the clast-lithological composition paralleled that seen at the SSSI, with <8% Greensand chert in the lowest exposed gravels, rising to 12–13% in the middle and ~20% in the uppermost gravel beds. The counts from the SSSI show an even more pronounced change, from only 2% Greensand chert in the beds classified as Lower Holland Gravel to ~25% in the uppermost deposits [10] (see Supplementary Materials Tables, Table S1). The recent temporary exposures (Figure 8), which allowed the sedimentology to be observed more clearly, showed palaeocurrents towards the NE or ENE, in keeping with flow in the palaeo-Thames–Medway valley. Sedimentary structures are suggestive of a braided cold-climate, gravel-bed river, with palaeo-flow likely to have been 200–300 cm/s during gravel transport, although an order of magnitude lower during the emplacement of the sand beds.

A single optically stimulated luminescence (OSL) dating sample was taken from a thick, well-sorted sand bed at the base of the temporary exposure, using a length of plastic pipe (see Figure 8, inset). An additional sample of the surrounding sand was taken for the dose-rate estimation. The OSL sample was processed in the usual manner, to give quartz-rich and K-feldspar-rich extracts in the grain-size range 180–250 µm [98]. OSL measurements were made using a Risø TL/OSL reader model 20, equipped with a calibrated ^{90}Sr/^{90}Y beta source. Blue (470 nm) stimulated signals (quartz) were detected through 7.5 mm of U-340 glass filter, and IR (850 nm)-stimulated signals (feldspar) through a combination of a BG3 and BG39 filter. The quartz equivalent dose (D_e) was measured using a single aliquot regeneration dose protocol [99,100], with 40 s of stimulation at 125 °C, a preheat of 260 °C for 10 s, and a cut heat of 220 °C. A final high-temperature stimulation

(280 °C for 40 s) at the end of each SAR cycle minimized any residual signal in the following cycle. Feldspar D_e were measured using a post-IR IR protocol [101] with a preheat/cut heat of 320 °C for 60 s, and stimulation at 50 °C and 290 °C (both for 200 s). For the feldspar, the final high-temperature IR stimulation at the end of each SAR cycle was at 325 °C for 200 s (Table 2).

Figure 8. Temporary cliff-top section at Holland-on-Sea, Essex, showing stratigraphy and sampling for luminescence dating (inset). Tendring District Council encouraged research on the site as part of their stakeholder engagement with local interest groups, which was facilitated by Mott MacDonald, the overall developers of the scheme, and their contractors, Jacksons.

Table 2. Radionuclide concentrations and total dose rates.

Sample Code	Depth (cm)	^{238}U (Bq/kg)	^{226}Ra (Bq/kg)	^{210}Pb (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	w.c. (%)	Quartz Dose Rate (Gy/ka)	K-Feldspar Dose Rate (Gy/ka)
186401	200	3.8 ± 1.3	8.1 ± 0.2	10 ± 2	11.1 ± 0.2	117 ± 3	32	0.67 ± 0.02	1.61 ± 0.07

Notes: (i) Water content (w.c., expressed as % of dry weight) is the mid-point between the measured present-day and saturated water content. (ii) Total dose rates contain a cosmic ray contribution calculated according to [102]. (iii) An internal dose rate of 0.02 ± 0.01 Gy/ka from internal U, Th is included in the quartz dose rate, consistent with [103]. (iv) The K-feldspar dose rate contains a contribution to the beta dose rate to 180 to 250 µm grains from internal ^{40}K (and Rb) in the K-feldspar lattice structure, based on an assumed K concentration of 12.5 ± 0.5% and Rb concentration of 400 ± 100 ppm [104,105]. A further contribution of 0.10 ± 0.02 Gy/ka is derived from internal U and Th [106].

For the measurements, quartz aliquots (8 mm diameter) were mounted on stainless steel discs (9.8 mm diameter) using silicone oil. Feldspar aliquots (2 mm) were similarly mounted in stainless-steel cups. The quartz OSL signal was dominated by the fast-component [107] (data not shown) and signal summation was from 0 to 0.8 s of stimulation, with a background based on the signal in the following 0.8 s. The feldspar signals were summed from 0–2 s of stimulation, with a background from 180–200 s.

Dose recovery tests were undertaken to examine whether the chosen protocols were able to measure a known dose accurately [108]. For quartz, the aliquots were bleached at room temperature for 100s s using blue light in the reader, followed by a 10 ks pause to empty the 110 °C TL trap, followed by a further room temperature bleach. The feldspar aliquots were bleached in a Hönle SOL2 solar simulator for 24 h. After bleaching, the aliquots were given a known dose using the beta source, and this dose was then measured in the usual manner. For the quartz, the ratio of measured to known dose was 1.11 ± 0.06 (n = 3, given dose = 110 Gy). For the $pIRIR_{290}$ signal from the feldspar, the corresponding ratio was 0.96 ± 0.06 (n = 4; given dose 360 Gy) and 1.00 ± 0.09 (n = 4; given dose 720 Gy). In both feldspar experiments, a measured background residual of 49 ± 4 Gy (n = 4) was subtracted from the measured signals before the comparison with the given dose. It is thus concluded that, for both the quartz and feldspar signals, the chosen protocols were able to achieve accurate measurement of a known dose given to the grains before any thermal pretreatment.

Radionuclide concentrations, measured using high-resolution gamma spectrometry [109,110], were used to estimate the dose rates. The sample was dried, ground, ignited at 400 °C for 24 h and finally cast in wax in a defined cup-shaped geometry. The cup was then stored for >20 days to allow ^{222}Rn to build up to a secular equilibrium with ^{226}Ra, before counting for 24 h. The resulting radionuclide concentrations (Table 2) were converted to infinite matrix dry beta and gamma dose rates using the conversion factors of Guérin et al. [111] and corrected for the estimated mean water content (Table 2).

Equivalent doses determined using the chosen protocols are presented in Table 3, together with the resulting luminescence ages. The IR_{50} signal is known to be unstable and, therefore, is expected to underestimate the age. Quartz ages based on doses greater than about 150 Gy usually underestimate the true age, for reasons that are unknown (e.g., [112]), although in this case the quartz age is indistinguishable from the feldspar $pIRIR_{290}$ age. Pawley et al. [113] also reported successful dating back to MIS 12 using quartz OSL in the Middle Thames valley. Nevertheless, in view of the known quartz behaviour in this dose range, the $pIRIR_{290}$ age is preferred. This age is a good match with the Anglian glaciation of MIS 12.

Table 3. Equivalent doses and luminescence ages. ('n' is the number of aliquots).

Sample Code	Sample	IR_{50} D_e, Gy	(n)	$pIRIR_{290}$ D_e, Gy	(n)	OSL D_e, Gy	(n)	Uncorr. IR_{50} Age, ka	Uncorr. $pIRIR_{290}$ Age, ka	OSL Age, ka
186401	OSL 1 Upper Gravel	298 ± 14	18	662 ± 26	18	252 ± 17	36	186 ± 12	412 ± 25	375 ± 29

5. New Data: Early Post-Anglian

5.1. Foxhall Road, Ipswich

Falling within the Anglian glacial limit, the Foxhall Road Palaeolithic site is a former brick pit within a narrow over-deepened valley in the SE outskirts of Ipswich. It was subjected to archaeological excavation a number of times in the early decades of the 20th century [56,114–116], before being developed for light industry. White and Plunkett [57] revisited the archival material relating to the site, principally at Ipswich Museum and the Suffolk Record Office. From Layard's and Smith's field notes, they were able to reconstruct and reinterpret much of the geoarchaeology. An opportunity for reinvestigation arose in 2005, when the site was redeveloped.

The erstwhile brick pit lies in the now dry headwaters of the Mill River on one of several pockets of 'brickearth' laid down in deeper parts of the valley, which probably represent subglacial scours. The sediment body is mapped as glacio-lacustrine by the BGS (DiGMap), falling within the glacio-fluvial gravels of the Gipping outwash fan (Figure 3). Each excavation showed differences in the stratification (Table 4), as the beds were not always continuous and showed variation in colour, but there was consensus that the sequence comprises mostly clay and silt, coarsening to fine sand and sporadic gravel, indicating a variable water flow, predominantly gentle but with occasional storm-generated high-energy phases.

Table 4. The sequence at Foxhall Road, according to different authors.

Layard (see [56])	**Smith (1921)**	**Boswell & Moir (1923)**
Topsoil		
Upper sand and gravel	Sand	Bed 2 (fine reddish gravel)
Gravelly clay	Reddish and dove pug	Bed 3 (stony reddish sandy clay: pug)
Red and grey clay (white sandy clay)	Stiff grey clay (brickearth)	Bed 4 (laminated dove brickearth)
	Red band *a*	Bed 5 (blue brickearth)
	Red & dove pug (brickearth)	Bed 6 (sandy brickearth)
White gravelly clay		
Red gravel	Red band *b*	Bed 7 (gravelly sandy loam)
Grey clay	Pure grey clay	Bed 8 (sandy loam)
(? Dark band)	Red band *c*	
Bone bed (various sand & gravel)	Sand, shingle, gravel	? Beds 9–12 (various sands, gravels, clays)

Correlating the data from boreholes and test pits from the 2005 excavation showed that much of the site represents a lake with a feeder stream at its northern end (Figure 9), from which proximity the artefacts were discovered. Layard's and Smith's field notes record sloping sediments, probably the marginal slopes of the lake or a delta from the feeder stream, with breaks in the sedimentation, overlain by horizontal strata, indicating a change from the lacustrine to a fluvial environment, in which sands and gravels, showing much higher energy levels, were deposited, probably under cool–cold climatic conditions, and suggesting the eventual development of an integrated drainage system [44].

An early post-Anglian age for the sequence is evident from a number of lines of evidence [58]. Till was found at depth, succeeded by gravel with flint clasts of greater angularity than those found in the pre-Anglian Kesgrave gravels, as well as *Rhaxella* chert: both indicators of glacial outwash. The heavy minerals include tourmaline, rutile and staurolite, with the addition of less durable minerals, such as kyanite and apatite, that are common in the glacial deposits but lacking in the Kesgrave Thames gravels. Changes within the trace and rare-earth elements found in the brickearth are partly due to weathering, with more quartz (SiO_2) and less calcium (CaO), manganese (Mn), phosphorus (P_2O_5), nickel (Ni) and potassium (K), which are all acid soluble, in the upper part. However, some of the variation can be attributed to changes in the catchment, with durable zircon and several lanthanides being more common in the middle and upper parts, possibly associated with the evolution of the drainage from a localized immature, partly lacustrine system following glaciation, to an integrated, fully fluvial drainage system, tapping new sources of material and bringing in additional minerals.

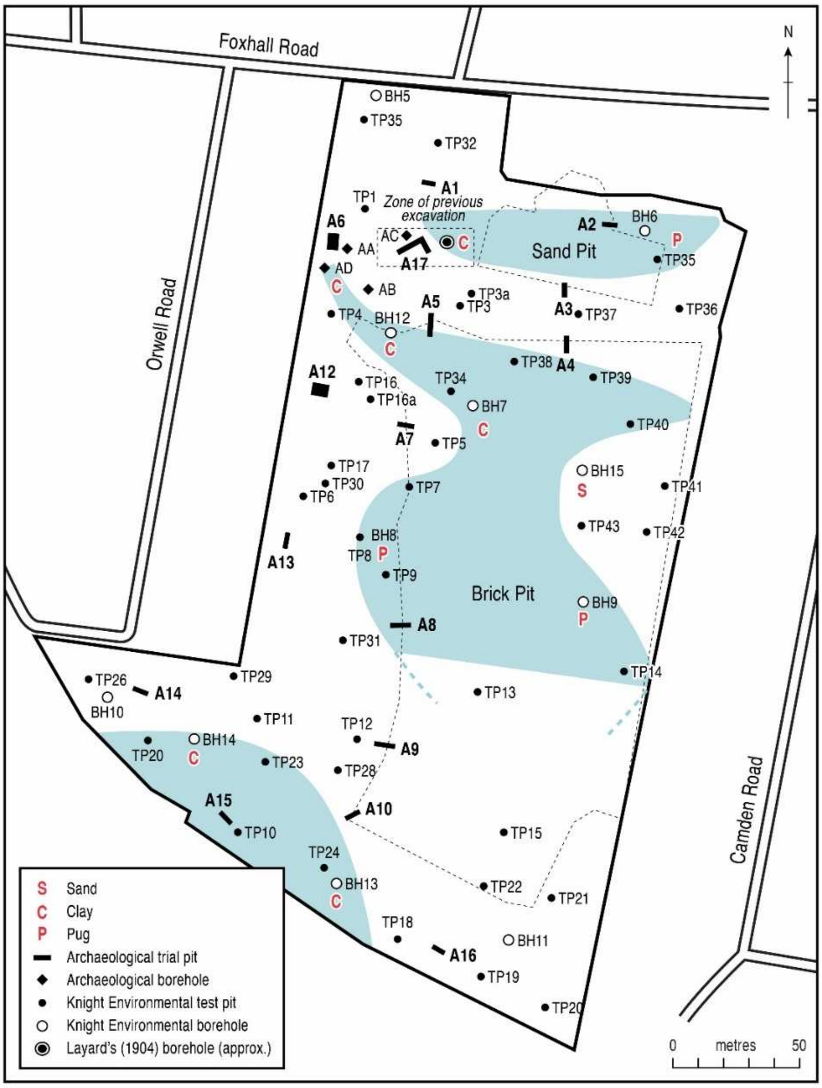


Figure 9. The Foxhall Road site, showing the extent of the palaeolake deposits (shaded).

No vertebrate bones or pollen were recovered from the brickearth, but a sparse freshwater ostracod fauna from its lower part (*Cyclocypris* and *Ilyocypris*) may be regarded as consistent, at least, with the vegetated margin of a lake or pond fed by a stream. This is in keeping with the sedimentological data. Palaeolithic artefacts were found throughout the sequence, with primary-context Acheulian occurrences in the Grey Clays and Red Gravels. The hand-axes from the Grey Clays were predominantly ovate, several with twisted edges, whereas those from the Red Gravels were predominantly pointed; these are attributable to Roe's (1968 [94]) Groups VI and II, respectively [86,87]. This sequence is similar to that found at Hoxne, but the reverse of the pattern at Swanscombe [86,87,117]. OSL dating [118] gave the results of 416 ± 36 ka (at 5.6 m depth) and 434 ± 54 (4.5 m depth). Although the dates are inverted, they are reasonably close and lie within one another's error ranges. This again confirms a late MIS 12–early MIS 11 age.

5.2. Spring Meadow School, Upper Dovercourt

Another site likely to represent an early post-Anglian episode, this time outside the glacial limit, is located at Upper Dovercourt, on the southern side of the Stour estuary. A prolific source of Lower Palaeolithic artefacts, this coincided with a gravel working known as Gant's Pit, or by the name of the erstwhile Pound Farm, which was located on the north side of 'Main Road', opposite the junction with Frank's Lane (now Road). The pit does not appear on historical Ordnance Survey maps but is thought to have coincided with land now occupied by a primary school (Spring Meadow School) and playing field. The former pit was the richest source of hand-axes (208 in number) in Essex [119–121] and was also a source of mammalian fossils, with beaver, rhinoceros, fallow deer, red deer, ox (aurochs) and straight-tusked elephant listed [121]. The hand-axe assemblage has been placed with those from the Swanscombe Middle Gravels and from Hoxne in Roe's Hand-axe Group II (see above; Figure 7) [94], although the occurrence of a significant number of twisted hand-axes at Dovercourt suggests that elements of Roe's Group VI are also present. The latter group is also believed to represent hand-axe making during MIS 11, possibly during MIS 11c in East Anglia and MIS 11a in the Thames [86,87,117].

In the late 1980s, sampling from temporary exposures in footings for a southward extension of the school buildings (Figure 10) revealed Palaeolithic flakes in situ in the gravel (an analysis of these samples appears in Supplementary Table S1), demonstrating that the gravel beneath the school is the same as that exploited in Gant's Pit. A limited program of excavation was undertaken in the grounds of the school in 2001, comprising two trenches, A and B (Figure 10). Numerous Palaeolithic flakes, predominantly soft-hammer flakes from hand-axe production, were recovered from Trench A, whereas Trench B yielded no finds but revealed an interesting sequence of finer-grained and partly laminated sediments, although their water content prevented deeper excavation. In November 2006, a mechanical excavator was used to dig temporary trial pits (1 and 2, Figure 10) adjacent to proposed new play areas to the west and east of the school buildings, and a further pit (3) was excavated in the SE corner of the site to assess the nature of the surviving deposits. Once below the depth of 1.2 m, health and safety considerations meant that the trial pits could not be entered, and the sediments had to be examined and sampled from the excavator bucket. It was possible to study the upper parts of the sequences at close hand, but these were generally not of the greatest interest.

Trench 1 was dug through the tapered edge of a mound of made ground (two separate phases of made-ground emplacement were evidenced by two buried topsoil layers: Figure 10). This made ground probably represents the infill of the former Gant's Pit. Beneath the made ground, and ~1–1.5 m below general ground level, a sandy gravel was exposed, within which a number of artefacts and mammalian fossil fragments were found. Only 0.8 m of this material survived above the London Clay (Palaeogene) bedrock (Figure 10). The presence of artefacts implied that this was a lateral extension of the deposit exposed in 2001 in Trench A. The fragmentary fossils, which were indeterminate, were the first to be discovered since the original gravel pit was in operation.

Trench 2 was located so as to cut through a break of slope that consisted of a shallow declination towards the north. No mound of possible quarry spoil was seen here, the break of slope instead having the appearance of a cut feature. The trial pit revealed no in situ gravel, but instead a thick sequence of silty/clayey sand, which became fresh grey-coloured and distinctly laminated with depth. This was proved to 3.6 m below the surface but could not be bottomed. Likely to be a continuation of those recorded in 2001 in Trench B, these sediments had characteristics strongly suggestive of an estuarine environment, but no corroborative fossils were encountered.

Trench 3 revealed only 0.5 m of gravel, beneath gravelly subsoil and lying above Pliocene Red Crag, the latter recognized from its characteristic plethora of marine shells. This previously unrecognized remnant of Red Crag was bottomed on to London Clay (Figure 10).

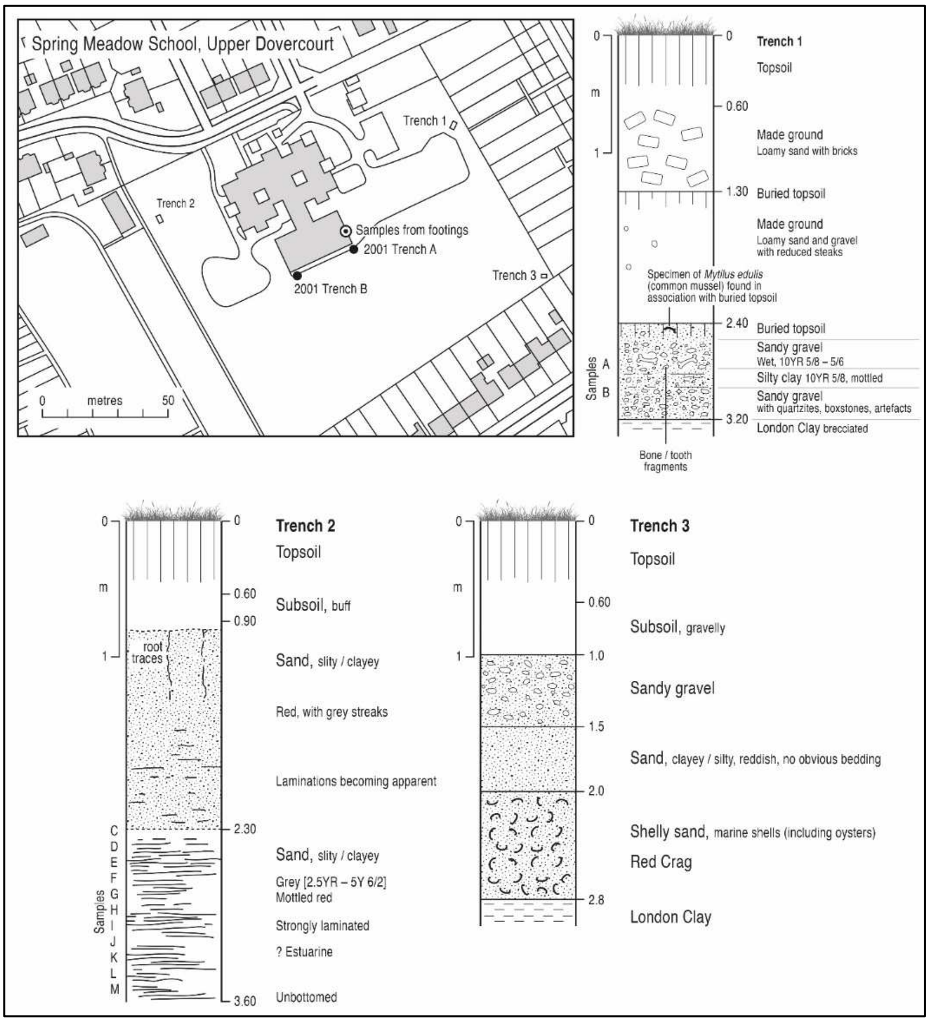


Figure 10. The 2006 investigation at Spring Meadow School, Upper Dovercourt, the site of the former Gant's Pit (Peter Allen, David Bridgland, Danielle Schreve and Mark White). The location of the three depicted trenches, as well as those excavated in 2001 and the sampling point during the 1980s, are shown in the plan (top left). Bone fragments and artefacts were found in the sandy gravel below 2.4 m in Trench 1.

In 2014, an archaeological assessment was undertaken on land at Pound farm, immediately WSW of the previous site. This involved fourteen test pits, although only two were excavated beyond a shallow depth. Both the main superficial facies reported from Spring Meadow School were recorded here, including laminated silt/sand clay proved to four metres below the surface in test pit 6, with evidence of possible cryoturbation and buried land surfaces in the upper 1.5 m (Figure 11). Gravel with possible Palaeolithic artefacts was also demonstrated at the site. In the 2014 test pit 12A, gravel was seen to overlie the laminated beds; this is a significant observation, as these two facies had previously been seen only in lateral relationship.

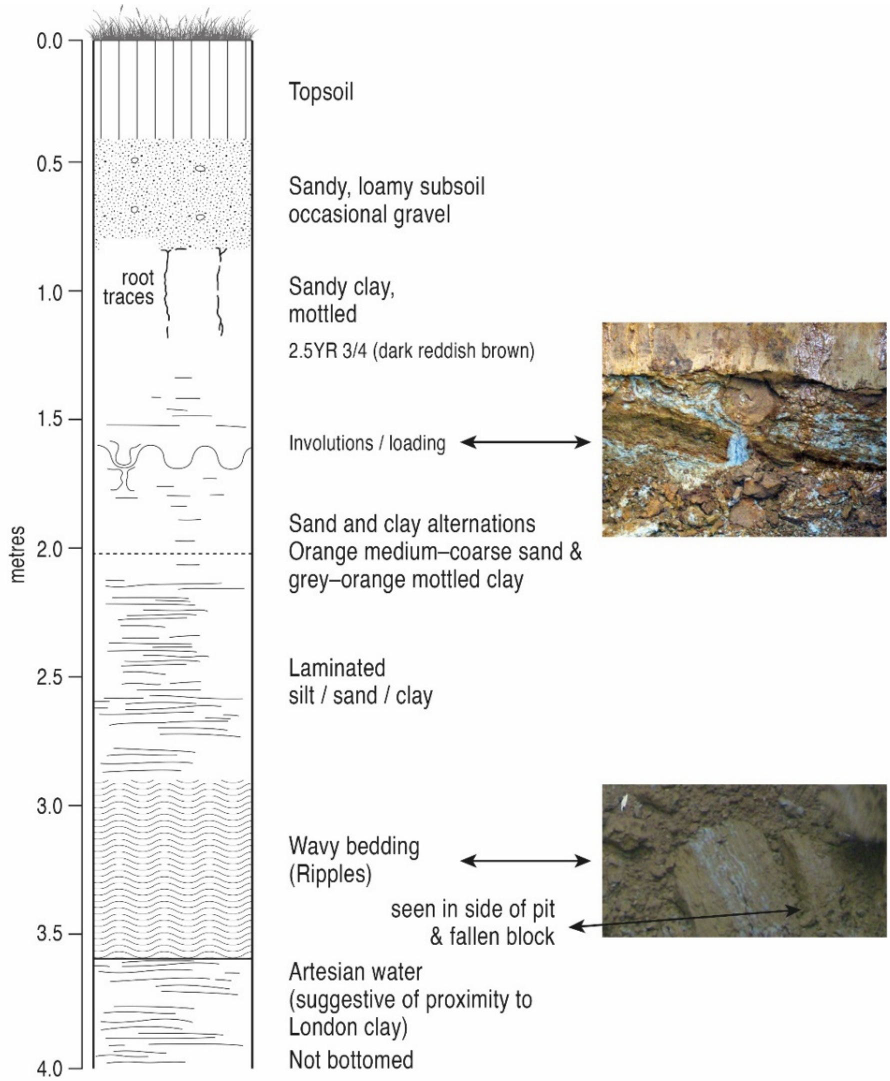


Figure 11. The Pound Farm 2014 archaeological assessment, test pit 6, the deepest excavated at the site. Photographs are inserted to illustrate cryoturbation and/or loading structures and ripple-laminated sediments.

There remain important unanswered questions about the recent findings from Upper Dovercourt. These include, in particular, the relation of the laminated silts, clays and sands to the artefact-bearing gravels, as well as the environment of deposition of the former and their affinity, or otherwise, to the River Stour. It is possible that they represent an estuarine facies of the Stour terrace deposits at Dovercourt, potentially a lateral equivalent of the Hoxnian estuarine beds at Clacton-on-Sea, on the opposite side of the Tendring peninsula (see below). If so, they could add valuable knowledge of Hoxnian sea-level history, of importance as part of the context for the Clactonian Palaeolithic type locality, as well as the Acheulian (hand-axe) industry at Dovercourt itself. At the present site, these laminated deposits would appear to reach ~20 m above the ordnance datum, which is significantly higher than the 8 m O.D. maximum height of the Clacton Estuarine Beds [122,123].

It is important to note that, in the inner/upstream reaches of a tidal estuary, the high-tide levels are related to, but likely to be significantly higher than, the contemporaneous sea level. It should also be noted, in consideration of the evidence from Upper Dovercourt, that upstream equivalents within the contemporaneous Thames system of the Clacton Channel intertidal deposits reach ~10 m O.D. at East Hyde, near Tillingham [124–129]. Further afield, in the Fen Basin at Woodston (near Peterborough) and in the valley of the River Nar (near Kings Lynn), tidally influenced deposits of less certain age-equivalence to Dovercourt reach ~14 m and ~23 m, respectively. The ostracod assemblages at Woodston comprise typically freshwater species but include some that are tolerant to low-brackish salinities, together with brackish-water *Cyprideis torosa* and *Loxoconcha elliptica* [130]. A sequence of pollen-dated Hoxnian sediments, the Nar Valley Clay of West Norfolk, yielded ostracods and diatoms suggestive of a marine regressive phase towards the end of the interglacial, although, unfortunately, the studied borehole only penetrated the top of the underlying Nar Valley Freshwater Member, which was barren [131]. Earlier work on the Nar Valley sequence, based on ostracods and foraminifera from archive samples [132], suggested a slightly deeper depositional environment for marine sediments that may represent an earlier phase of the interglacial. Recent work has suggested that separate MIS 11 and MIS 9 sea-level highstands can be distinguished in the Nar Valley, with the older ones recording a transgression to 18 m O.D. [133]. In this context, it is also worth noting that recent and continuing investigations at two MIS 11 lacustrine sites westwards/inland of Dovercourt show ostracod evidence of saline influence that probably resulted not from proximity to the sea or estuaries, but from either saline groundwater intrusion or (less likely) evaporative enrichment. In the Hoxnian and post-Hoxnian lacustrine sequences at Marks Tey (up to 27 m O.D.), the euryhaline *Cyprideis torosa* is a persistent component of assemblages that are otherwise typical of fresh waters, though potentially tolerant of slightly saline waters [55,134]. At Little Cornard (Snelling, Allen, Horne, Lord, Sohar, unpublished), on the northeastern slope of the Stour valley (c. 35 m O.D.), lacustrine freshwater ostracod assemblages with brackish-tolerant species, including *Sarscypridopsis aculeata*, are associated with freshwater molluscs [135] and *Chara*.

If the Upper Dovercourt sediments do indeed include an estuarine component, the stratigraphical position of the Palaeolithic gravels, above and therefore later than the implied high-sea-level event, of probable Hoxnian age, is relatively in keeping with evidence from sites such as Swanscombe, where the assemblages with twisted ovate hand-axes, which might be broadly time-equivalent to Dovercourt, are associated with the uppermost deposits and from late in the interglacial (e.g., [9,136]).

An alternative explanation for these potential estuarine sediments must be considered, however. They could be an unfossiliferous estuarine facies of the Red Crag and, therefore, significantly older than the Stour terrace gravels. That interpretation, although considered the less likely of the two, is plausible on account of the newly discovered occurrence of the Red Crag outlier at Upper Dovercourt. If microfossils were to be found in these sediments, this issue would be readily resolved. The presence of a basal gravel separating the deposit from the London Clay bedrock would also provide an indication of its affinity, provided that the character of the gravel could be determined from the analysis. Obtaining such further data requires deeper excavation than has proved possible to date.

The extant Acheulian assemblage from Dovercourt consists of ~175 hand-axes, two roughouts, 26 thinning flakes, 72 flakes, nine scrapers and cores [91]. Most are in sharp condition, although some are rolled and many are riddled with later frost damage, leaving them fragile. S.H. Warren [122], for whom workmen recorded the position of each find, noted a correlation between the depth and patination/staining: (2–3 ft = white; 3–6 ft = mixed; 6–9 ft = unchanged), but concluded that the finds were contemporaneous, having all been swept off a nearby land surface. The hand-axes are mostly pointed forms with an important cordiform element, several of which are twisted. As already noted, it is likely that both Roe groups now thought to be correlated with MIS 11 are represented, II and VI (Figure 7). It is thus probable that, like Foxhall Road, Swanscombe and Hoxne, Dovercourt preserves industries belonging to different parts of MIS 11. The same is true of Hitchin [117]. Further work is needed to establish the sequence of industries at these sites, and how this relates to the patterns detected north and south of the Thames.

5.3. The Clacton Channel Deposits

Work on the Hoxnian (MIS 11c) interglacial deposits at Clacton, which form part of the first post-diversion terrace of the Thames–Medway (Figure 4E), has continued in recent years. This has included monitoring of the foreshore on the northern side of the Colne estuary and of temporary exposures in the urban area, such as building work at the seaward end of Trafalgar Road (2000) and on the northern side of the Nelson Road (2006 and 2019), which adjoin the sea-front road, Marine Parade West (Figure 12). The Trafalgar Road site, now 'The Anchorage,' is ~120 m WSW of what has been termed the 'Palace Hotel' site, which is actually the redevelopment of the former Palace Theatre complex, the location of borehole investigations in the 1970s (Figure 12b) [123,136].

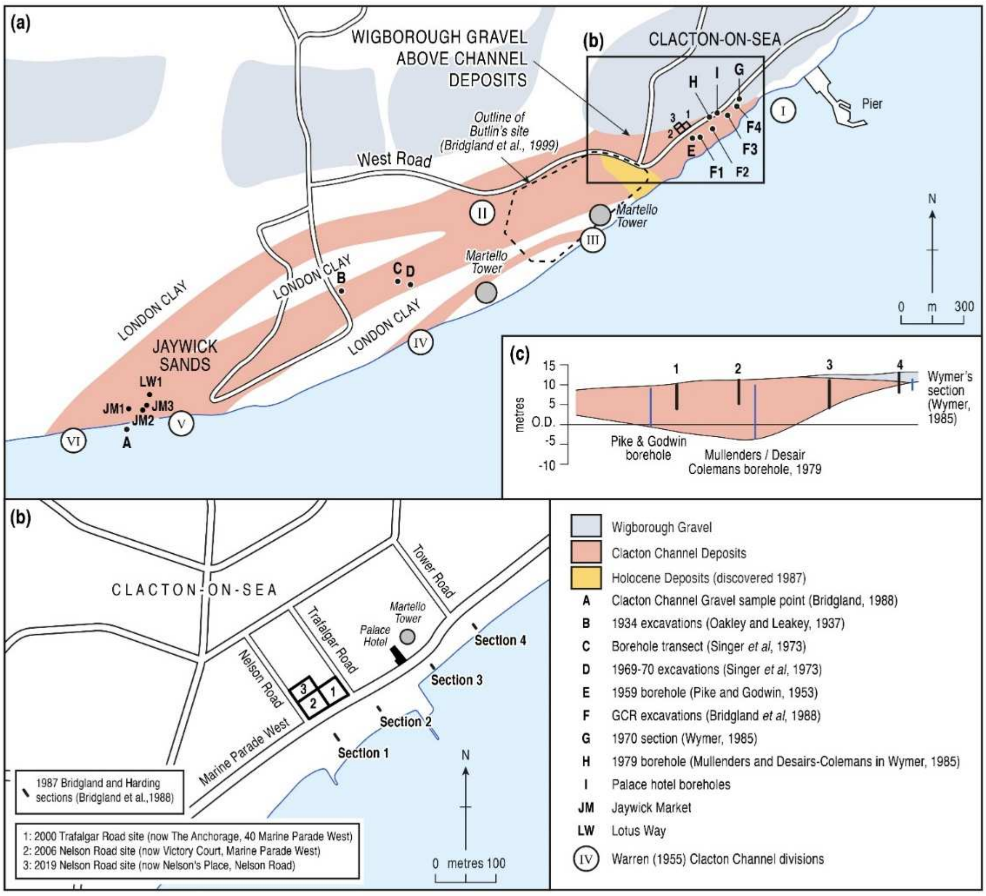


Figure 12. Quaternary sites at Clacton-on-Sea, showing the footprint of the complex of interglacial channels (**a**). Part (**b**) is an enlargement of the area around Marine Parade West, showing the locations of the recent development sites that have yielded new data and the various temporary exposures in the West Cliff during the 1980s. Part (**c**) shows the section through the channel derived from those exposures and neighbouring boreholes.

5.3.1. Trafalgar Road

Work conducted here in 2000 was associated with the building of a new apartment block, The Anchorage (actually 40 Marine Parade West). The sieving of spoil heaps from the largely unmeasured piling resulted in a comprehensive list of typical Clacton Channel fauna, chiefly molluscs (Table 5) but also including bones and teeth of small mammals. Also found here were plant macrofossils (seeds) that provide a link with the adjacent 'Palace Hotel' borehole, including characteristic *Pyracantha* and *Najas minor* specimens (cf. [123]).

Table 5. Mollusca from the Clacton Channel Deposits, Trafalgar Road (identified by Richard Preece, 2006).

Valvata piscinalis
Valvata cristata
Ecrobia ventrosa
Belgrandia marginata
Bithynia tentaculata
Bithynia troschelii
Lymnaea stagnalis
Radix balthica (=*Lymnaea peregra*)
Hippeutis complanatus
Gyraulus albus
Segmentina nitida
Anisus vorticulus
Acroloxus lacustris
Carychium minimum
Succinea sp.
Truncatellina sp.
Vallonia excentrica
Vallonia costata
Aegopinella nitidula
Zonitoides excavatus [1]
Zonitoides nitidus
Discus rotundatus
Clausilia (*including pumila*)
Trochulus sp.
Cepaea sp.
Carychium minimum
Limax sp.
Unionids/Potomida littoralis [2]
Sphaerium corneum
Pisidium nitidum
Pisidium clessini
Pisidium amnicum
Pisidium moitessierianum
Pisidium henslowanum sp.

Notes: [1]—One specimen of this rare species was noted, found previously only by A.S. Kennard. [2]—Unionids were mostly fragmentary, but there were three reasonably intact valves that allowed specific identification.

5.3.2. Nelson Rd: Victory Court

The 2006 construction site, now Victory Court, involved two pilings (A and B) of 20 m in depth, reaching ~10 m below sea level. These yielded 900 kg of sediments that remain largely unprocessed, although subsamples have been picked for the ostracods and foraminifera (See Supplementary Table S2). The screw-auger technology in use meant that clear differentiation between the discrete levels is not assured, and a degree of contamination between the horizons is inevitable. However, distinct stratigraphical changes are nonetheless apparent, with striking differences between the levels at 1 m intervals. The data show mixing of freshwater and brackish taxa.

Bithynia opercula from these Clacton sites enabled amino-acid racemization (AAR) analysis [83,85] to address the issue of whether these deposits, long-attributed to the Hoxnian [137–140] and a source of the first interglacial pollen diagram (in 1953 [141]), date from MIS 11 or MIS 9. The Clacton specimens helped to cement the attribution of the suite of opercula analyses from Clacton, Swanscombe (also in the Thames) and the Hoxne-type locality to MIS 11.

Using ostracod assemblage data (from [123]), new mutual ostracod temperature range (MOTR) reconstructions [142] for the MIS 11 interglacial Clacton Channel Deposits contrast with today's maritime climate, being more continental, with mean July temperatures similar to those of the present day but with winters at least 2 °C colder. The somewhat restricted ostracod fauna newly recovered from the Clacton Channel Deposits at Victory Court (Supplementary Table S2) yields MOTR reconstructions that are wide-ranging but consistent with those based on the 1999 [123] assemblage.

5.3.3. Nelson Rd: Nelson's Place

The 2019 Nelson Road development site, for another apartment block (Nelson's Place), resulted in an archaeological assessment and trial-pit excavation. The trial-pit sections revealed only the weathered and decalcified upper portion of the Clacton Chanel Deposits (estuarine beds), with an overlying gravel in the SW part of the development area. BGS mapping suggests that the feather-edge of the Wigborough Gravel would be expected hereabouts, overlying the Clacton Channel Deposits (see Figure 12). A sample of this gravel was found to be compositionally similar (Supplementary Table S1) to counts of the gravel overlying the channel deposits in the 1987 West Cliff Section 4 [10], ~0.3 km to the NE, and to the Clacton Channel Gravel as sampled from the Lion Point foreshore and the Butlin's holiday camp redevelopment project [123].

6. New Data: Later Post-Anglian

6.1. Offshore Late Middle Pleistocene Sediments with Fossils and Artefacts

In 2014–2015, a beach replenishment scheme transported ~863,000 m^3 of recharge material to the coastline between Holland-on-Sea and Clacton-on-Sea (Figure 3), forming a beach 18 m wide (cf. [143]). Offshore Licence Area 447, approximately 18 km east of Walton on the Naze (Figure 1) and covering an area of 9.2 km^2, was the source area. Given the chronological and spatial extents of known Pleistocene terraces in the area, as reported in this paper, the pre-extraction archaeological assessments correctly reported a high potential for Palaeolithic archaeology within the Area 447 deposits. The difficulties of demonstrating this potential, however, resulted in no active investigation prior to their extraction and re-deposition. Nonetheless, as soon as the beaches re-opened, local collectors (citizen scientists) began to amass a substantial number of Pleistocene mammalian remains and lithic artefacts from the redeposited sands (Figures 13 and 14).

Figure 13. Mammalian teeth from the beach recharge between Clacton and Holland-on-Sea. Top row, mammoth (*Mammuthus* sp.); middle, woolly rhinoceros (*Coelodonta antiquitatis*); bottom row, horse (*Equus* sp.) Photos: John Ratford.

Figure 14. Flint artefacts from the beach recharge between Clacton and Holland-on-Sea. Top, from the left, Levallois point, blade and two further points; bottom row, Levallois cores. Photos: John Ratford.

With support from Historic England, geophysical data and sediment cores from the aggregate companies involved (Tarmac Marine, Hanson Marine and CEMEX), and the continuing work of local collectors, current research is attempting to reconstruct the environmental context and original location of these artefacts. Analysis of the lithic artefacts has shown that a significant proportion of these (35%, n = 138) appear to be Middle Palaeolithic, showing clear signs of having been produced using the Levallois technique (Figure 14). The fresh condition of this material, in combination with the geoarchaeological assessment of the sediment cores, has refined their potential location on the seabed and led to palynological and luminescence analysis pointing towards Early Middle Palaeolithic occupation in an estuarine environment (Bynoe et al., forthcoming; see [144]).

The significance of this is two-fold. Firstly, increasing recognition of the Palaeolithic artefacts and Pleistocene mammalian fossils within offshore aggregates (e.g., Area 240 [145]) is leading to growing engagement with the offshore industry and the valuable data revealed thereby. The reuse of these data, the collection of which is generally outside the scope of most archaeological budgets, can provide new levels of information regarding the preservation and nature of submerged Pleistocene deposits and landscape developments. Secondly, the comparison of the Area 447 collection with known terrestrial Levallois assemblages and recent finds from the North Sea [145] is beginning to open up a more evidence-based discussion about the use of these now-submerged landscapes by hominins throughout the Early Middle Palaeolithic.

6.2. Stoke Tunnel–Maidenhall (Stoke Bone Bed), Ipswich

In addition to Foxhall Road, a second post-Anglian site of considerable importance is located within the area of greater Ipswich, variously termed Stoke Tunnel or Maidenhall, the names applying to the northern and southern ends of a discontinuous outcrop of a fossiliferous deposit known as the 'Stoke Bone Bed' [91,146,147]. Works associated with the railway, from its construction in the 1840s and again in 1948, uncovered faunal remains, including mammoth, bison and rhinoceros. In 1975, John Wymer exposed more of the bone bed and, at the same time, observations were made during the construction of drainage trenches for a new school at Maidenhall, with further excavations taking place at the school site in 1976 [91]. These excavations uncovered a nearly complete mammoth skeleton and the bones of horse, red deer, wolf and the aquatic tortoise *Emys orbicularis*.

Both the bone bed and underlying purple clays are sources of Palaeolithic artefacts, as well as vertebrate remains. Above the bone bed is an iron-stained sandy clay with poorly preserved mammalian bones and a thin gravel band (~0.5 m thick). Above this are 1.8 m of laminated clays and ~2.4 m of coarse red gravel. The combination of mammalian and archaeological evidence points strongly to MIS 7 as the age for these Maidenhall deposits, with the co-occurrence of horse and mammoth and of Levallois technology both acting as important indicators that preclude a correlation with other post-Anglian climate cycles [148–150]. This interpretation has been corroborated by AAR dating [85].

An archaeological evaluation and watching brief took place in 2002 in association with the construction of a combined sewerage overflow scheme in the grounds of Stoke High School at Maidenhall, Ipswich, with both archaeological and geological work carried out by and on behalf of the Essex County Council's Field Archaeology Unit [151]. Two geological sections were recorded during the sewerage construction, facilitating a limited palaeoenvironmental reconstruction. Although no artefacts or macrofaunal remains were recovered, a focused program of samples were collected and archived for future scientific analysis. Unfortunately, funding for such analyses has not been forthcoming.

6.3. Wrabness and Stutton Ness—Harkstead

Fossiliferous interglacial deposits occur at Wrabness, on the south side of the Stour estuary (Figure 3) [152]. John Wymer, who recorded a few flakes and two cores from the foreshore at Wrabness, believed them to have been derived from a low, gravelly cliff that he thought likely to equate with sites at Stutton and Harkstead on the northern side of the estuary, which have produced similar finds of both fauna and artefacts [91,121]. The Wrabness deposits consist of brickearth and sand, overlain by cryoturbated sand and gravel. Faunal remains include the bivalve *Corbicula fluminalis*, which is regarded as indicative of interglacial conditions and a pre-Ipswichian/Eemian age [9,153]. The occurrence of *Equus ferus* (horse) similarly precludes a Last Interglacial age, while *Mammuthus primigenius/trogontherii* (mammoth) is a strong indicator of MIS 7, just as at Maidenhall, Ipswich (see above, [148]). Other less biostratigraphically diagnostic mammalian components of the fauna are *Cervus elaphus* (red deer), *Bos* or *Bison* (aurochs or bison) and *Palaeoloxodon antiquus* (straight-tusked elephant). The discovery of several Palaeolithic flint artefacts further confirms a pre-Ipswichian age for the sediments, given that hominins are believed to have been absent from Britain between MIS 6 and MIS 4 inclusive [154]. These artefacts include Acheulian hand-axes and Levallois flakes, the latter very much in keeping with the suggested MIS 7 age (again, comparison with Maidenhall, Ipswich, is worthwhile; see above). Investigations in progress (Snelling, Lord, Horne) on these deposits on both sides of the Stour have produced additional evidence from ostracods: freshwater assemblages come from both Wrabness and Stutton Ness, with the addition at the latter of noded forms of *Cyprideis torosa*, indicative of brackish water, close to the upstream limit of tidal influence.

6.4. Clacton-on-Sea Channel iii–iv

The original mapping of the Clacton Channel sediments by S.H. Warren (e.g., [122]) revealed a fully separate narrower channel to the SE of the main complex. The two ends of this narrower channel were given separate numbers by Warren, at points where they intersected the coast and were exposed on the foreshore: his iii and iv (Figure 11). Well aware that these were probably two ends of the same channel, Warren considered them to be part of the Clacton Channel complex and attributed their infill to the Clacton Estuarine

Beds [122]. He noted the correspondence of fauna in the various parts of the complex, with straight-tusked elephant (*Palaeoloxodon antiquus*) and the bivalve *Potomida littoralis* present throughout, although he illustrated Channels iii, iv and vi as containing only the Estuarine Beds, which were not the primary source of vertebrate fossils and artefacts in the main Clacton Channel exposures. In particular, he recorded from Channel iv the occurrence of *P. antiquus*, together with "an oyster-bed with a profusion of *Littorina*, and also the *Tapes decussatus*" ([122] p. 288), also noting that "non-marine Mollusca were absent" and not mentioning any artefacts. These observations have led to the suggestion that the sediments filling Channel iii–iv are significantly different from the Clacton Estuarine Beds, the molluscan assemblage from the latter being dominated by non-marine taxa. Furthermore, the Channel iii–iv estuarine sediments extend below modern ordnance datum (as do those in Warren's Channel vi), significantly lower than the base of the Clacton Estuarine Beds in the original West Cliff exposures. Although Warren would appear to have attributed this to changes to the lateral facies and inter-facies erosion, later authors have proposed that the Channel iii–iv infill represents the post-Hoxnian River Colne [9,123], a view that is in keeping with its smaller dimensions and the fact that the species now termed *Venerupis decussata*, which was not recorded from the main Clacton Channel complex, occurs only in post-Holsteinian deposits in the Netherlands [155].

In 1987, the redevelopment of the erstwhile Butlin's holiday camp at Clacton led to an archaeological investigation, the camp having been built over the main Clacton Channel complex between the West Cliff and Jaywick Sands exposures, as well as above Warren's Channel iii (Figure 11) [123]. The work at Butlin's rekindled interest in the Clacton deposits, and foreshore exposures of Channel iii–iv at Jaywick were monitored whenever possible in the following years by David Bain, before the exposures were obscured by sand from beach recharge, as part of a major coastal defence scheme in 1999. In the mid-1990s, the Channel iii–iv deposits were manifested as mottled orange-grey silty clay with embedded marine shells, notably oysters (*Ostrea* sp.), cockles (*Cerastoderma edule*) and mussels (*Mytilus edulis*), contrasting with the familiar adjacent blue-grey Holocene estuarine clay with *Scrobicularia plana*. The presence of large, securely embedded white bones made for further interest. There were exhaustive searches for Clactonian artefacts, but none was forthcoming, despite the sieving of perhaps 0.3 tonnes of material. Observations of the sediments covered an area of ~150 m by 15 m and showed them to be up to 0.5 m thick, at an elevation of ~1 m O.D. and often occurring in pockets. The latter features might represent scour hollows, such as were observed at the 'Hippopotamus site' at East Mersea, on the opposite side of the Colne estuary, where interglacial sediments attributed to MIS 5e occur in similar pockets on a foreshore cut in London Clay [9]. The Jaywick molluscs are predominantly extant species, although some have very contracted modern ranges. Especially notable are the air-breathing snails *Segmentina nitida* (shining ramshorn), *Anisus vorticulus* (little whirlpool ramshorn), *Truncatellina cylindrica* and *Vertigo angustior*. Also found were the bivalves *Pisidium clessini* and *Corbicula fluminalis*, which would appear to indicate a pre-Ipswichian/Eemian age [153,156]. However, they were recovered in small numbers, evidently eroded and suggestive of derivation, either from upstream or from earlier deposits. The presence of *Venerupis* (*Tapes*) provided a valuable link with Warren's observations of his Channel iii–iv. Identified vertebrate remains comprised *Bos primigenius* (aurochs), including four teeth, two large horn-cores, an atlas, two right humerus distal ends, a left tibia and a right calcaneum. Straight-tusked elephant (*Palaeoloxodon antiquus*), previously recorded by Warren, was confirmed in the form of a complete right first molar of an 8–10-year-old animal. A shed right antler base of *Megaloceras giganteus* and a right third metacarpal of *Ursus arctos* were also identified. Isolated bones of a small herpetofauna were studied by Dr Chris Gleed-Owen. They included a right ilium and left humerus of *Bufo bufo* (common toad) and an indeterminate snake maxilla with six tooth sockets. Various frog (*Rana*/*Anura* sp.), lizard/salamandid and other fish bones were also found.

A small sample of ostracods and foraminifera pointed to a brackish creek, with estuarine ostracods (e.g., *Cyprideis torosa* in smooth form only) and a very low-diversity foraminiferal assemblage, with a few freshwater ostracods also present. Some of the ostracods encountered were probably reworked from the nearby Hoxnian Clacton Channel Deposits. It is perhaps significant that these and other proxies suggest that the Channel iii–iv sediments have a stronger estuarine signature than the main Clacton Channel Deposits.

This work has provided important indications of the age of Channel iii–iv. *Bithynia tentaculata* was present amongst the Mollusca, despite Warren's assertion that non-marine molluscs did not occur in his Channels iii and iv. AAR analysis of *Bithynia* opercula from these sediments has enabled their attribution to the Ipswichian Stage (MIS 5e) [83,85].

Small mammals were chiefly represented by water vole (*Arvicola terrestris cantiana*), with >100 teeth recovered. This taxon has evolved quite rapidly over the last three million years, with distinct dental differences evident and of value for gaining an indication of age. Ten teeth were measured in terms of the enamel thickness quotient and yielded SDQ (Schmelzband-Differenzierung-Quotient) values averaging 110. These results concur with the AAR data, pointing to the Ipswichian Interglacial (MIS 5e) for this channel of the palaeo-Colne.

7. New Data: Last Climate Cycle

7.1. Upper Palaeolithlic Material from the Holland Brook Valley at Thorpe-le-Soken

Flint artefacts have been recovered from the parish of Thorpe-le-Soken from 1980 onwards by field-walking on a steep bluff, up to 20 m above O.D., overlooking a distinct bend in the Holland Brook. Located less than 1 km downstream from Daking's Pit, these finds represent multi-period flint scatters, including material from the earlier Palaeolithic and later prehistoric. They are, however, dominated by a notable later Upper Palaeolithic assemblage of over 40 pieces. Tools include Creswell points, burins, end scrapers, and steeply backed and bruised blades that were examined by the late Dr Roger Jacobi and Prof. Nick Barton and illustrated by Hazel Martingell [157]. As these were surface finds, there is, unfortunately, no stratigraphical context. The distinct tool typology and variety is, however, suggestive of regular seasonal occupation over millennia of what might have been a strategic site overlooking this small valley, particularly under the fluctuating climatic conditions of the Upper Palaeolithic.

7.2. Holocene Sediments in the Colne Estuary: Lotus Way and Jaywick Market

Archaeological assessments in association with the Clactonian type locality took place in November 2017 and March 2021 at Lotus Way and Jaywick Market, respectively Figure 11). The investigation involved the mechanical excavation of trial pits, trenches and boreholes sunk using a hand-held Cobra percussion corer. Both sites are adjacent to Lion Point and lie within the mapped extent of the Clacton Channel Deposits, specifically Warren's Channel v (Figure 11). At both locations, however, no Pleistocene sediments were observed; instead, Holocene marine clay was found to overlie the London Clay bedrock directly.

At Lotus Way, where the ground surface was 1.7 m O.D., the London Clay surface was reached at −2.45 m O.D. and was overlain by a 2 cm layer of coarse sand, perhaps representing a lag deposit, and then by 3.68 m of dark grey to dark greyish-brown silty clay and 0.45 m of made ground. Diatoms from the silty clay, from between −2.15 and −1.15 m O.D., were predominantly marine and brackish forms, notably *Paralia sulcata*, a tychopelagic form common in the benthos and plankton, and *Rhaphoneis amphiceros* and *Metascolioneis tumida*, which confirm a marine origin [158]. Also present was *Diploneis smithii*, which is suggestive of less saline conditions. Above this level, diatoms were largely absent, presumably due to post-depositional dissolution.

At Jaywick Market, three boreholes were put down on behalf of Momentum Ltd. The erosive contact with the London Clay rises here towards the east from −3.10 to −1.74 m O.D. Diatom preservation was variable in the seven samples taken through the silty clays, but, again, marine conditions were confirmed, with *P. sulcata*, *Podosira stelligera* and *M. tumida* present at −2.8 m O.D. in the westernmost borehole. There was also a change to less saline conditions, as shown by abundant *Navicula peregrina*, a common salt-marsh form, together with *Pinnularia* sp., which suggests a freshwater input at 0.73 m O.D. in the easternmost borehole.

It is likely that both sites represent the fill of a Holocene tidal inlet occupying a pre-existing channel cut into London Clay, probably corresponding to that described and illustrated from the foreshore and cliff exposures by Warren ([89] cf. his Figure 4) and observed (with *Scrobicularia*) by David Bain in his monitoring of the foreshore (see above). The sampled sediments differ markedly from the Holocene tufa and overlying shelly, polleniferous and silt encountered in the NE corner of the Butlin's Holiday Camp site, ~3 km to the ENE of the Jaywick localities [123]. The more easterly deposits were attributed to deposition in a spring hollow and showed no sign of marine influence, the silt yielding a terrestrial mollusc fauna and pollen of cereals, pointing to the latter half of the Holocene. The occurrence of *Discus rotundatus* in the tufa indicates that it post-dates 8500 BP (cf. [159]).

8. Discussion and Synthesis

8.1. Profound Quaternary Landscape and Drainage Changes over the Last ~10 Climate Cycles

The research area, southern coastal East Anglia, has experienced major changes during the course of the Quaternary. Prior to the Anglian glaciation, it coincided with the lower reaches of the Thames–Medway river system, which was feeding north-eastwards across East Anglia into the western flank of the Rhine–Thames delta, a long-standing sediment sink that occupied the southern North Sea Basin (see above). The delta was probably subsiding gently under the load of sediment, but the British land mass experienced uplift during the Quaternary, an isostatic effect driven by erosion and the transfer of material into the delta [63]. Increased erosion in response to greater climatic severity following the Mid-Pleistocene Revolution and the advent of the 100 ka glacial–interglacial cycles caused more rapid uplift in the Middle and Late Pleistocene, manifested in the staircase of river terraces formed on the left (NW) side of the Thames valley (Figure 5) [9,38].

The Middle Pleistocene also saw the Bytham (Ingham) River become the principal drainage system of southern Britain, carrying sediment from the West Midlands into East Anglia, where it was initially confluent with the Thames [24,25]. The progressive SE migration of the Thames saw the Bytham, by the start of Low-level Kesgrave deposition (early Cromerian Complex), draining independently into central Suffolk, whereas the Thames was confined to northern Essex and SE Suffolk (Figure 2). Such was the situation when the Anglian ice sheet arrived on the scene, obliterating the Bytham drainage system and diverting the Thames into its present valley through London and, offshore, from the North Sea Basin into the English Channel, in both cases as the result of glacial-lake overflow (see above; Figure 2). Initially, the diverted Thames re-joined its previous valley in NE Essex, but continued southward migration with each terrace cycle (perhaps accelerated in response to diversion via the Dover Strait [80,81]) drew the river progressively towards its Last Glacial course, preserved in the bedrock surface offshore from the present estuary [160].

As the Thames migrated southwards, rivers that had been initiated (in some cases as outwash streams) during Anglian deglaciation as its left-bank tributaries, such as the Blackwater and the Colne, developed their own interglacial estuaries into the North Sea. Rivers further north, such as the Holland Brook and the Stour, were probably part of the Thames system during sea-level lowstands. The post-Anglian interglacial half-cycles are all recorded within the fluvial archives of these rivers, with the notable exception of MIS 9, which is, however, represented just to the south of the research area in a River Colne deposit at Cudmore Grove, East Mersea (Figure 3) [161,162]. Combined ostracod- and beetle-based palaeoclimate reconstructions of MIS 9 at Cudmore Grove and Thames–Medway sites to the south have provided consensus mean monthly palaeotemperature ranges, indicating summers at least as warm (if not warmer) than those of the present day, but winters at least 2 °C colder, suggesting a more continental climate akin to that of present-day northern Germany [163].

8.2. The Inter-Related Palaeolithic Record

The archaeological record in Britain has been extended back in time greatly in the last two decades, potentially to the Early Pleistocene, on the basis of two coastal sites in the area north of that under consideration: Pakefield and Happisburgh (Figure 2) [69,70,164]. These are both closely associated with the fluvial record, the former coinciding with a late Middle Pleistocene estuary of the River Bytham, whereas the latter shows a Thames influence, in that Lower Greensand chert occurs there, albeit that the site is within the Wroxham Crag area (see above). As the impact of these sites becomes fully embedded in the subject, they represent a potential paradigm shift in the understanding of pre-*sapiens* hominin occupation in Britain and NW Europe. An important implication is that artefact assemblages from the Low-level Kesgrave Thames terrace deposits can be regarded as potentially indigenous, rather than, by definition, intrusive or representative of later superimposed sediments. This applies, for example, at Daking's Pit (see above). Another advance that promises a more prominent role for Palaeolithic archaeology in the deciphering of the Quaternary record is the recognition of the fact that hand-axe morphology can have geochronological significance, based on the typological research of Derek Roe in the 1960s [86,87,94,117].

8.3. Differences between the Glaciated and Non-Glaciated Areas

Within the research area, there are marked differences in the nature of the fluvial archive, in particular that part of it dating from the climate cycle that followed the highly disruptive Anglian glaciation, between the locations within the ice limit and those beyond it. Thus, the Hoxnian (MIS 11(c)) sites of Foxhall Road and Marks Tey (the latter somewhat to the south of the area under close consideration) reveal lake deposits in basins created by glacial processes (see above), such lakes being essentially restricted to recently deglaciated landscapes [165]. The post-Anglian evolution of the drainage associated with these lakes thus marked the transition from the glacial landscape to the beginnings of the modern river system. The comparison with the MIS 11 deposits at Upper Dovercourt and the Clacton Channel Complex, which are beyond the glacial limit, is stark. These represent interglacial fluvial or fluvio-estuarine archives that are only a little or not at all different from those of any other Middle–Late Pleistocene temperate episode. In both pairs of examples, there is a contrast of scale, smaller versus larger, respectively, in each case. Many of the differences reflect the disruption of drainage systems and other geomorphological settings by glacial and, in particular, deglacial processes, the latter leaving a landscape with mounds of chaotically arranged sediment and closed hollows where late-surviving ice has melted. The last-mentioned produced the kettle holes that provide a plethora of lacustrine interglacial archives for MIS 11 in East Anglia [137,166], between which emergent drainage systems struggled to (re)establish their courses. In addition, there are larger-scale over-deepened channels and valleys, as represented at sites such as Marks Tey. This post-glacial landscape can be explained and understood with reference to the concept of paraglaciation, developed over the last half century (e.g., [167,168]) and incorporated, although not necessarily named as such, in consideration of the Holocene fluvial archives that represent the drainage recovery following the MIS 2 glaciation [169,170].

8.4. The Value of Developer Funding and of Work by Learned Societies and Citizen Scientists

The advances reported in this paper have not been achieved as a result of well-funded research projects, although early 21st-century initiatives resourced by the Aggregates Levy Sustainability Fund saw valuable new work undertaken on the Medway and Thames–Medway deposits in eastern Essex and on former quarry sites in that county as a whole [84,88]. Much of the work described here has been undertaken as part of opportunistic research projects, following up historical finds, as developer-funded archaeological assessments required by government planning guidance [171], or by the monitoring of known find-spots and source areas to record exposures and recover fossils and/or artefacts as part of what might now be termed 'citizen science' (e.g., [172,173]). The archaeological assessment system can provide the impetus for geological and palaeontological work to enable an improved understanding of the sedimentary contexts for prehistoric hominin and human activity [171]. However, no equivalent mechanism is in place for maximizing knowledge attainment when developments occur that impact important Earth-science sites. The UK system of statutory geoconservation sites (SSSIs and rare National Nature Reserves: NNRs) and non-statutory local geosites provides some basis for the recording and sampling of threatened sites [174–177], while the BGS can have a role in site recording and the archiving of samples and boreholes (https://www.bgs.ac.uk/geological-data/national-geological-repository/ accessed on 23 August 2022; https://www.bgs.ac.uk/information-hub/borehole-records/ accessed on 23 August 2022). There is much dependence, however, on the time expended by interested citizens who are prepared to monitor and investigate sites in their local areas, without whom much valuable information would be lost. Their work can be seen on the websites of GeoSuffolk, GeoEssex and the Essex Field Club, as well as on similar internet sources more widely. Notable examples of such citizen science are seen in the contributions to this paper, e.g., by David Bain, who has monitored and collected material from sites at and around Clacton, and by Andrew Snelling in his work at Little Cornard, Wrabness and Stutton Ness. William George of the Essex Field Club, a long-term citizen scientist, has monitored and published findings on the sites at Harkstead, Stutton Ness, Wrabness, Walton-on-the-Naze and East Mersea [152,178–181]. Rosalind and Ian Mercer, both active in the Essex Rock and Mineral Society and GeoEssex, have been greatly involved throughout the county [182], producing information leaflets, establishing geoconservation sections and recording new road and quarry exposures. Their intervention secured access to the Holland-on-Sea cliff-stabilization works, enabling recording and sampling, including for the OSL date reported above. Paul Buisson and John Ratford's collection of material from the recharged beaches at Holland and Clacton has produced spectacular material (see above, Figures 13 and 14) [183].

Learned societies have an important role in organizing and underpinning work of this type, ranging in scope from the Geologists' Association, with its regional and affiliated groups (many of which oversee the selection and management of non-statutory geo-conservation sites), to county groups, such as GeoSuffolk and GeoEssex, the Essex Rock and Mineral Society and the Essex Field Club. Some of these groups often have annual publications (Essex Naturalist, Transactions of the Suffolk Naturalists' Society) dating back to the 19th and early 20th centuries, archives of historically important geological and archaeological papers, as well as occasional publications, newsletters and websites providing information about local sites and geological themes. The UK's Quaternary Research Association (QRA) has contributed greatly since its initiation in the 1960s, with its numerous conferences and field meetings, and associated field guides, and through its international spin-off, the Fluvial Archives Group (FLAG), the instigator of this special issue.

The classic citizen-science project is an undertaking that requires large amounts of labour, often over lengthy periods and at regular intervals, such as the examples reported here of exposure monitoring. Across many branches of science, there have been well-organized projects set up by academic researchers and designed to make use of interested 'amateurs' who can be trained to collect data that are then pooled and processed. In the case of the various Quaternary projects undertaken here, these have generally been citizen-led, with interested local geologists and natural history enthusiasts building up knowledge and collections of valuable material on their own initiative, with no requirements for training (they are self-trained to a high level); their interaction with academics has often been fruitful, however, and was sometimes required for confirmation of identifications. The highly successful monitoring of the recharged Clacton–Holland beaches is a prime example, leading to hugely valuable collections being amassed and fruitful collaboration with those prospecting offshore for the submerged source deposits (see above).

9. Conclusions

Significant advances in our understanding of the SE marginal area of the Anglian (MIS 12) glaciation of eastern England have been achieved in recent years, as reported here, from the varied combination of multi-disciplinary approaches. Highlights of the contributions presented here include:

(1) The confirmation of the Anglian age of the glacial blockage of the Thames, as demonstrated by the OSL dating of the Upper Holland Gravel;
(2) The suggestion, based on artefact typology, that the Daking's Pit hand-axe assemblage might be pre-Anglian, and therefore indigenous to the Cooks Green Gravel;
(3) The discovery, from the monitoring of beach recharge, of new sources of Middle Palaeolithic archaeology, probably MIS 7 deposits exposed offshore;
(4) The confirmation from AAR geochronology of the Last Interglacial (MIS 5e) age of the subsidiary Channel iii–iv at Clacton.

While much has been accomplished by academic workers, with doctoral research being well represented, considerable contributions have come from developer-funded geoarchaeological assessments and others have been made by dedicated citizen-science participants, locally based monitors of exposures and sediment accumulations. This paper summarizes these advances in recent decades in the context of the reconstruction of drainage evolution, Quaternary climate changes (glacial–interglacial cycles and marine isotope subcycles) and hominin occupation, with the understanding of the last, in particular, being revolutionized in the first two decades of this century. The record from this area represents an impressive and geochronologically well-constrained archive of value for comparison with other peripheral glaciated regions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/quat5030037/s1. Table S1. 16–32 mm Clast-lithological data from the unglaciated periphery of southern East Anglia; Table S2. Fossil material recovered during deep piling of the Clacton Channel Deposits at Victory Court, Nelson Rd, in 2006 (compiled by J. Whittaker).

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