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Abstract

Late Middle Pleistocene Thames-Medway deposits in eastern Essex comprise both large expanses of Palaeolithic artefact-bearing river sands / gravels and deep channels infilled with thick sequences of fossiliferous fine-grained estuarine sediments that yield valuable palaeoenvironmental information. Until recently, chronological control on these deposits was limited to terrace stratigraphy and limited amino-acid racemisation (AAR) determinations. Recent developments in both this and optically-stimulated luminescence (OSL) dating make them potentially powerful tools for improving the chronological control on such sequences. This paper reports new AAR analyses and initial OSL dating from the deposits in this region. These results will help with ongoing investigation of patterns of early human settlement.

Using AAR, the attribution by previous workers of the interglacial channel deposits to both MIS 11 (Tillingham Clay) and MIS 9 (Rochford and Shoeburyness Clays) is reinforced. Where there are direct stratigraphic relationships between AAR and OSL as with the Cudmore Grove and Rochford Clays and associated gravels, they agree well. Where OSL dating is the only technique available, it seems to replicate well, but must be treated with caution since there are relatively few aliquots. It is suggested on the basis of this initial OSL dating that the gravel deposits date from MIS 8 (Rochford and Cudmore Grove Gravels) and potentially also MIS 6 (Dammer Wick and Barling Gravels). However, the archaeological evidence from the Barling Gravel and the suggested correlations between this sequence and upstream Thames terraces conflict with this latter age estimate and suggest that it may need more investigation.

Keywords: OSL, AAR, Palaeolithic, fluvial terrace sequence, Thames-Medway

1. Introduction

Eastern Essex is a crucial region for understanding Late Middle Pleistocene human occupation of the landscape, being both geologically and archaeologically very rich. Geologically, the interglacial deposits preserved within deep channels are much more extensive than those preserved further upstream in the Thames, allowing more detailed palaeoenvironmental reconstruction (e.g. Roe et al, 2009; 2011). Additionally, the river gravels are directly correlative with the main Lower Thames sequence, on which there is considerable chronological control (e.g. Bridgland, 1994; 2006).

The region (Figure 1) is located between the rich archaeological sites of Swanscombe (Bridgland, 1994, p. 193-218) and Clacton (Warren, 1955; Bridgland et al., 1999), at both of which there is evidence for two different industries superimposed within a single interglacial period: Clactonian and Acheulian. In contrast, in eastern Essex, although there is a wealth of interglacial deposits, all the artefacts reported in the 30 sites listed in the English Rivers Palaeolithic Project (Wessex Archaeology, 1996; 1997), where securely provenanced, are associated with gravels thought to be deposited within cold stages. Furthermore, most of the finds are of handaxes – i.e.

Acheulian. Warren (1933) reported two artefacts that he described as typically Clactonian from the Asheldham Gravel between Burnham-on-Crouch and Southminster (Wessex Archaeology, 1997). However, these are not securely provenanced, neither are there sufficient artefacts to convincingly suggest the presence of a Clactonian industry. There is also limited evidence for Levallois material in the region, from Martin's Farm Pit at Great Stambridge (Wessex Archaeology, 1996). This is the only record of Levallois from the Barling Gravel and again it is not well provenanced. All the other artefacts associated with the Barling Gravel are handaxes, for example at Baldwin's Farm (Wessex Archaeology, 1996; Wenban-Smith et al., 2007a).

Developing a robust chronology and depositional history for these deposits is therefore crucial to our understanding of landscape development and human occupation of the region. For many years, establishing a chronology for river terrace sequences was dependent on methods such as biostratigraphy and the use of archaeological artefacts as tie-points. Over the past ten years, however, it has become increasingly viable to use the absolute dating method of optically stimulated luminescence (OSL) to estimate age in these contexts. This method involves measurement of a signal that is built up in the crystal lattice of sand-sized quartz and feldspar grains and is proportional to the length of time since the sample was last exposed to light. It is therefore very applicable to fluvial terrace sequences, in which sand beds are more common than fossil material. Early studies were concerned that the signal might not reset or 'zero' properly in a fluvial environment, but recent work suggests that this is only problematic for young samples (i.e. < 5 ka, e.g. Wallinga, 2002, Briant and Bateman, 2009). At the time of this study, saturation of the signal at higher doses / older ages and an associated scatter in age estimates meant that the practical limit of the technique on sand material from lowland Britain using the standard SAR protocol with late background subtraction (Murray and Wintle, 2000) was around 350 ka (e.g. Toms et al., 2005; Briant et al., 2006). However, as this is based on sample characteristics rather than standard half-lives, such limits cannot be applied uncritically in all contexts. Since then, isolation of the fast component using early background subtraction may have increased this limit in these contexts to c. 450 ka (Pawley et al., 2010). Use of early background subtraction is easy to implement within a SAR protocol and it has recently been suggested by Cunningham and

Wallinga (2010) that this should be done routinely to address age underestimation in both old and young samples.

The most robust results from OSL are obtained when samples are dated from multiple sedimentary units within the regional stratigraphy and the results obtained can be cross-checked against each other. This approach has recently been used in a number of sand-dominated river systems where material suitable for other dating techniques was not present (e.g. the Rhine-Meuse delta, sequences spanning the last 235 ka, Tornqvist et al., 2000, Busschers et al., 2005; the Roer Valley Graben, where the base of the sequence is dated to c. 450 ka, Schokker et al., 2005; and the Tagus (Tejo) river in Portugal, where the highest terrace dates to > 300 ka, Martin's et al., 2009). Within the British Isles, this approach was recently pioneered in the Solent Basin and Sussex Coastal Plain (Bates et al., 2004; 2007; Bates and Briant, 2009; Bates et al., 2010; Briant et al., 2006). Similar work has also been undertaken further west in the Palaeolithic Rivers of South West Britain (PRoSWeB) Project (e.g. Brown et al., 2010).

In contrast, in eastern Essex, because of the deep channel fills present in this region, it is possible to create an integrated chronology using not just OSL dating, but also AAR. Amino acid racemisation (AAR) analyses were also undertaken in the Solent / Sussex work, but a lack of comparable terrestrial mollusc material between sites made the results of little use for building a regional chronology (Bates et al., 2004; Collins and Penkman, 2004). AAR too is a method where recent advances in sample selection, preparation and analysis have greatly increased its utility (see Penkman, 2010). The aim of the *Medway Valley Palaeolithic Project* (MVPP), funded by the Aggregates Levy Sustainability Fund through English Heritage, was to extend the successful methodology applied to the Solent to developing an improved framework for Thames-Medway Pleistocene terrace deposits in both Essex (Wenban-Smith et al., 2007a; Schwenninger et al., 2007; Penkman et al., 2007) and Kent (Wenban-Smith et al., 2007b), in relation to the archaeological record from these regions. This is crucial if the archaeological patterns in this region are to be compared both with the upstream Thames system and further afield.

This paper reports the chronological framework arising from the Essex part of the project, based mostly on OSL and AAR, with some input from archaeological evidence. It should be noted that the OSL ages are based on a limited number of aliquots and should therefore be regarded as initial age estimates only.

Figure 1 here

2. Pleistocene Geology of eastern Essex

The study area (Figure 1) is defined by the River Blackwater to the north and the Thames to the south, with the River Crouch separating the Southend and Dengie peninsulas, running east-west. Topographically, the area is low-lying (largely below 20 m O.D., with a maximum height in the west of c. 70 m O.D.), and underlain by Tertiary beds – mostly London Clay, but also Bagshot and Claygate Beds.

British Geological Survey (BGS) mapping of the Southend and Dengie peninsulas in the 1970's (e.g. Lake et al., 1986) recognised several altitudinally distinct gravel bodies, frequently covered with predominantly fine-grained 'head' or 'brickearth' deposits thought to be aeolian or periglacial in origin. Bridgland (1983a,b; 1988; Figure 1) split the gravel deposits into: (1) a High-level East Essex Gravel characterised by Wealden Medway lithologies (Bridgland, 1994) and (2) a Low-level East Essex Gravel marked by an influx of local and exotic lithologies typical of gravels in the Lower Thames (Bridgland, 1980). The high-level gravels are less continuous and interpreted as dating from an earlier, pre-Anglian period when the Medway flowed north across eastern Essex, becoming confluent with the Thames on the Tendring Plateau north-west of Clacton (Bridgland, 1995). The low-level gravels, in contrast, post-date the late Anglian (MIS 12) diversion of the Thames southward into its present valley taking over the lower valley of the Medway, converging with it north of the Hoo Peninsula (Gibbard, 1977; 1979). The combined Thames-Medway initially flowed north along the former course of the Medway, crossing eastern Essex and entering the North Sea near Clacton (e.g. Bridgland, 1983a,b). Following this, the substantially larger Thames gradually overwhelmed the Medway, and the distribution of the lower, more southerly, gravel units shows that the Thames-Medway gradually migrated clockwise to its current position (e.g. Bridgland et al., 1993), with the Medway now clearly established as a south bank tributary of the Thames. A number of different nomenclatures and correlations have been proposed for these deposits (Table 1).

Table 1 here

In association with these gravel deposits there is a series of low-lying channels, often with gravel at the base, infilled with fine-grained interglacial deposits containing fossils mostly with estuarine affinities (Lake et al., 1977; 1986; Roe, 1994, 1999). There are seven significant channel fragments reported in eastern Essex including the archaeologically-significant Clacton Channel deposit (e.g. Brown, 1840). These occur at different altitudes in relation to sea-level, as does the marine transgression recorded within the deposits (Roe, 1999). The channels have been classified as ‘high-level’ (Tillingham / East Hyde and Clacton) channels, ‘intermediate’ (Rochford) and ‘low-level’ (Shoeburyness, Barling, Burnham and Cudmore Grove) channels (Roe, 1999). The high-level channel deposits that have been studied have pollen with high frequencies of *Abies* and *Picea* and a ‘Rhenish’ molluscan fauna (Bridgland et al., 1999; Roe, 2001; Table 4). These are correlated with the estuarine deposits at Clacton, and the Phase II deposits (Lower Middle Gravel and Upper Middle Gravel) at Swanscombe and attributed to the Hoxnian Stage. In contrast, the intermediate and low-level deposits are less biostratigraphically distinctive (Roe, 1999; Roe and Preece, in press).

Bridgland et al. (2001) also described a high-level Southend Channel, originally reported by Whitaker (1889), although no palaeoenvironmental analysis has been reported from it. A further extremely deep channel is reported 5 km to the east of Burnham on Crouch at East Wick (Lake et al., 1977, Figure 1). In addition, there are other spatially-restricted interglacial deposits that do not fit into this framework. For example, in the foreshore at Cudmore Grove the East Mersea Restaurant (Bridgland et al., 1995) and Hippopotamus Sites (very laterally-restricted but thought to be equivalent – Bridgland and Sutcliffe, 1995) contain vertebrate evidence that suggests an Ipswichian (last interglacial) age for these fragments (Bridgland, 1994; Roe et al., 2009). At Clacton there are several channels: a high-level channel c. -4 to 8 m O.D. best exposed at West Cliff (Warren’s 1955 channel i) and associated lower-level channel remnants at c. -1 to 3.5 m O.D. to the south west (including the deposits at

Butlins studied by Bridgland et al., 1999). A Holocene channel is also present at c. 1.5 to 2.5 m O.D. near the Martello Tower (Bridgland et al., 1999).

In this paper, the age of these deposits will be tested against the stratigraphic succession proposed by Roe and Preece (in press, Table 2). This is a revised version of Bridgland's (2003, 2006) schemes (Table 1) with additional insights from biostratigraphy, aminostratigraphy and the sea level data set (Roe, 1999, 2001, Roe et al., 2009).

Table 2 here

3. Methods

3.1 Sampling

The aim of the MVPP was to re-sample all the mapped gravel bodies and channel deposits in eastern Essex, providing a better-constrained chronological framework for fluvial and estuarine deposition in the study area. Field investigation and sampling focussed on quarry sections where these were available and test pits where they were not. In addition archive material from Shoeburyness (borehole S1 – Roe et al., 2011) and East Hyde (borehole EH1 – Roe, 2001) was reinvestigated and samples retrieved for AAR. Sieving for archaeological artefacts was undertaken in all test pits. Samples were also retrieved for AAR and OSL where suitable material (shells and sand) was available. The retrieval of suitable material for AAR also enabled a limited new molluscan analysis to be undertaken and this is reported in Table 4. Microfossil analysis was also undertaken and is reported in Wenban-Smith et al. (2007a). In addition, an intact block sediment sample was collected at a coastal section in Southend (TQ 87955 85150) thought to possibly expose deposits of the Southend Channel overlying Southchurch Gravel (Figure 5, Table 3). A thin section from here was made in order to analyse the microstructure for sedimentary features diagnostic of the depositional environment.

Stratigraphic details of all the sequences are reported in Wenban-Smith et al. (2007a). These come from the Rochford Gravel (Doggetts Farm), Barling Gravel (Barling Gravel Pit), Dammer Wick Gravel (Burnham Wick Farm) and the Cudmore Grove Gravel (Cudmore Grove); also the Rochford Clay (Apton Hall Farm), Shoeburyness

Clay (Shoeburyness borehole), deposits within the Southend Channel (Southend cliff), East Wick Channel deposits (East Wick), Tillingham Clay (Bradwell Hall test pits and East Hyde borehole) and East Mersea Restaurant site (Cudmore Grove). In addition, following the completion of the project, material became available from the East Wick Channel, where the base of the channel deposits reaches -30 m O.D. Data and shell material studied by A.S. Kennard from these deposits were discovered by one of the authors (SP) in the Natural History Museum after the end of the MVPP. Table 3 gives details of the stratigraphy of those sections, test pits and boreholes from which data is reported in this paper, including boreholes thought to describe the East Wick borehole from which Kennard's samples came.

Table 3 here

Table 4 here

3.2 Amino Acid Racemisation analysis

Amino acid racemisation provides a relative geochronology for shell-bearing deposits, based on the degradation of amino acids within proteins in the shell since the death of the organism. New techniques have sought to increase robustness and avoid contamination by isolating the 'intra-crystalline' fraction of amino acids, thought to have degraded within a closed system (Sykes et al., 1995; Penkman et al., 2008a). It has been found that the intra-crystalline fraction of calcitic opercula from the snail *Bithynia* sp is a particularly robust repository for the original protein (Penkman et al., 2008b; in press). Therefore, this material was chosen for use in this study and all values reported in this paper are from such opercula. The development of chromatographic methods able to separate the D- and L-forms of multiple amino acids (Kaufman and Manley, 1998), rather than just the single L-isoleucine / D-alloisoleucine pair (yielding an A/I value), provides isochronic information and helps identify compromised samples. Amino acid data (some of which originated from A/I studies) is reported here from all the estuarine channel fills studied by Roe (1994, 1999, 2001, et al., 2009, 2011) with the exception of the Burnham Channel at North Wick. Re-drilling of this site during MVPP fieldwork succeeded in extending the sequence 6 m below that of Roe (1994, 1999; and Preece, in press), but did not yield freshwater shells or *Bithynia tentaculata* opercula. It should be noted that AAR from the Cudmore Grove Channel (Roe et al., 2009) was not part of the MVPP study, and that the Shoeburyness AAR included in the MVPP study has previously been published (Roe et al., 2011). AAR from the Barling Channel was previously reported by Penkman (2008b, also in press). In addition, archive material from the East Mersea restaurant site was included in the MVPP study despite the lateral restriction of this sequence. Data is also reported from archive material from the East Wick Channel (BGS borehole TQ99NE/45A, grid reference TQ 9995 9647, Table 3).

All samples were prepared using the procedures of Penkman (2005) and Penkman et al. (2008a) to isolate the intra-crystalline protein by bleaching. Two subsamples were then taken from each shell; one fraction was directly demineralised and the free amino acids analysed (referred to as the 'Free' amino acids, FAA, F), and the second was treated to release the peptide-bound amino acids, thus yielding the 'total' amino acid concentration, referred to as the ‘Total Hydrolysable amino acid fraction (THAA, H*). Samples were analysed in duplicate by RP-HPLC (Penkman et al., 2007).

During preparative hydrolysis both asparagine and glutamine undergo rapid irreversible deamination to aspartic acid and glutamic acid respectively (Hill, 1965). It is therefore not possible to distinguish between the acidic amino acids and their derivatives and they are reported together as Asx and Glx. Full details of AAR measurements are shown in Table 5.

Table 5 here

3.3 Optically-stimulated luminescence (OSL) dating

A large-scale programme of test-pitting was carried out to target mapped cold-stage gravel bodies for OSL dating. Gravels at the base of interglacial channel fills were often inaccessible, but a sand sample was successfully retrieved from a borehole taken from the Rochford Channel Gravel at Apton Hall Farm (Table 3). Otherwise, sand samples for optically-stimulated luminescence (OSL) dating were taken in opaque plastic tubing from vertical faces and stored in light-tight bags until processed. Sample locations were chosen to maximise the likelihood of zeroing before deposition and were usually clean, well-sorted sand beds. Samples were retrieved from all gravel bodies exposed at the surface. At the time of the analysis, the practical limit of OSL dating using the late background subtraction and standard SAR protocol of Murray and Wintle (2000) was c. 350 ka. For this reason, samples from the highest Thames-

Medway gravel bodies (the Southchurch and Asheldham Gravels) were not dated. There is therefore also a rich archive of samples from this project that could now be dated using advances in the technique that allow dating of older samples (e.g. Pawley et al., 2010).

Preparation to quartz involved separation of the modal size fraction by wet sieving and treatment with hydrochloric and hydrofluoric acids, removal of heavy minerals using sodium polytungstate and further dry sieving. Equivalent dose was determined in the Research Laboratory for Archaeology and the History of Art, Oxford, using automated Risø measurement systems with both blue diodes and green halogen light. The Single Aliquot Regenerative (SAR) protocol of Murray and Wintle (2000) was used, with the addition of a post-IR blue OSL procedure within the SAR protocol (Banerjee et al., 2001) to further minimise feldspar contributions and remove problems of anomalous fading. 6 small (2 – 4 mm) aliquots of sand-sized (125 – 180, 180 – 255 or 255 - 355 μm) quartz were measured (Table 6). Luminescence measurements were made at 125°C, with a default preheat 1 (PH_1) value of 260°C for 10 s, preheat 2 (PH_2) of 220°C for 10 s and up to 6 regeneration dose points. Equivalent doses (D_e) for individual aliquots were calculated using late background subtraction of the last 8 seconds from the first 0.8 seconds. The final D_e is a mean of 6 aliquots (Table 6), except for CG05-03 (X2461), where 5 aliquots were used because of an extreme outlier (Figure 3k). It should be noted that since these dates were undertaken, Rodnight et al. (2006) have stated that a minimum of 50 aliquots should be undertaken from fluvial OSL samples to ensure a representative sample. The ages presented in this paper should therefore be regarded as initial OSL age estimates only.

Table 6 here

Environmental dose rates were calculated only on the basis of geochemical analysis by ICP-MS using a fusion preparation method. In most cases, this is acceptable because the samples were taken at least 20 cm away from any sharp geological boundary and had a full 30 cm radius of homogeneous material around them. However, this was not possible for samples X2467 (DOGF05-03) and X2455 (BURN05-01) (see Table 3 for details), which should be treated with some caution. Radioisotope concentrations were converted to dose rates using the conversion factors of Adamiec and Aitken (1998) and grain-size attenuation factors of Mejdahl (1979).

Cosmic dose rates were calculated using the equation of Prescott and Hutton (1994) and it was assumed that overburden accumulated soon after deposition and was negligible relative to the burial period. Interstitial water content attenuates dose rates, and this was corrected for using the absorption coefficient of Zimmerman (1971). It was assumed that present-day moisture content is representative of water contents throughout burial (percentage dry weight of sample). Errors attached were 3% for samples with field moisture contents less than 10% and 5% for samples with field moisture contents more than 10%. This should capture the full range of uncertainty related to changing water content over time. In any case, even significant changes in water content have a fairly limited effect on age estimates (e.g. Briant et al., 2006). In all cases, water content values calculated from separate water content samples and discarded end parts of the OSL samples were in very close agreement. Full details of the OSL measurements, water content values and dosimetry data are shown in Table 6. These were previously reported in Schwenninger et al. (2007) where ages were calculated based on a subset of the aliquots used based on perceived deviation from the midpoint. They have now been recalculated from those presented in the original report by Schwenninger et al. (2007) to include all aliquots within 2 standard deviations of the mean (see Figure 3). Sample X3080 (APHF05-01) is presented for the first time and also includes all aliquots within 2 standard deviations of the mean. Ages were calculated by dividing the mean equivalent dose (D_e) ± one standard error (i.e. standard deviation / $\sqrt{n}$) by dose rate.

4. Results

4.1 AAR values

The analysis of the closed system of protein within shells allows a new methodology to be developed, which incorporates multiple amino acid data to give a measure of the overall extent of protein breakdown within a sample, the Intra-crystalline Protein Degradation (IcPD). The protein breakdown in the FAA and THAA fractions should be highly correlated and can be cross-plotted, giving an aminostratigraphic framework with younger samples lying at low values and older samples with higher values, given a similar temperature history for all the sites. A study has been undertaken of over 50 interglacial sites within the UK which has allowed the tentative correlation of the regional aminostratigraphic framework to the Marine oxygen Isotope Stage (MIS) record (Penkman, 2005; Penkman et al., 2008b, in press) and the Essex Medway samples have been compared to these (Figure 2). In addition to the samples dated as part of the MVPP, regional data is also presented from opercula from Clacton (Penkman et al., 2010) and Cudmore Grove (Roe et al., 2009). Channels of different ages are present at Clacton (Warren, 1955) but the material from Clacton presented here comes from samples correlated with the Lower Freshwater Bed within the Hoxnian channel at West Cliff, and is attributed on AAR and biostratigraphical grounds to the early part of MIS 11 (Bridgland et al., 1999; Penkman et al., 2010). The Cudmore Grove channel deposits are exposed on the foreshore of Mersea Island at Cudmore Grove. They are thought to have been deposited by a tributary of the Thames and to date from the later part of MIS 9 (Roe et al., 2009). All the MVPP samples showed closed-system behaviour, with the exception of one operculum from sample EH9.2Bto1bF (NEaar 3734) from the East Hyde (EH1) borehole, 9.2 m. This has abnormally low levels of protein degradation in the THAA fraction compared to that of the FAA fraction, indicative of a compromised system (Preece and Penkman, 2005). It was therefore removed from the dataset.

Figure 2 here

On the basis of the relative D/L values and concentrations (Figure 2) the amino acid data from the opercula from East Mersea Restaurant site, when compared with unpublished values from Quaternary sites within the UK (Penkman, 2005; Penkman et al., 2008b) are consistent with an age assignment within MIS 5e, i.e. the Ipswichian, as previously suggested (Bridgland et al., 1995). The amino acid data from the opercula from the other Medway channel sites investigated are all consistent with age assignments in the range MIS 9 to MIS 11. The mechanism of the protein breakdown reactions means that increased degradation occurs during warm stages and there is a slowing in the rates of degradation in cold stages (e.g. see Figure 2 in Miller et al., 1999). As little decomposition occurs in cold stages, and there is a degree of natural variability in biological samples, it can be difficult to discriminate the end of one warm stage from the beginning of the next (Penkman et al., 2008b) and the separation between the end of MIS 11 and the beginning of MIS 9 is particularly difficult using the amino acids presented here (Ashton et al., 2008; Roe et al., 2009). However, we conclude that the material from East Wick and Apton Hall Farm is likely to be from MIS 9, and that the samples from Bradwell Hall are consistent with an MIS 11 age (Figure 2).

The samples from Shoeburyness and East Hyde fall between the ranges of these two interglacials, and are therefore more problematic. Measurements from a number of interglacial sites from this period have shown that even when using opercula it is very difficult to tell the difference between some sites of MIS 9 and 11 ages (Penkman et al., 2008b, in press). This appears to be a genuine chemical overlap possibly related to limited racemisation during MIS 10, rather than reworking of shell material (ibid.). Given this overlap, the ages of these two channel deposits need to be suggested on other grounds. It is possible to use the pollen records from these sites to suggest which age is more likely. The opercula from Shoeburyness were taken from the base of the sequence in the 'pre-temperate' substage (cf. Turner and West, 1968) at the start of the interglacial (Zone I; Roe, 1999, et al., 2011; Figure 2), suggesting an early MIS 9 age is more likely. In contrast, those from East Hyde were sampled from sediments containing 'late-temperate' substage (Turner and West, 1968) pollen assemblages (Zones IIIa and IIIb; Roe, 2001; Figure 2), suggesting that late MIS 11 is more likely. This latter suggestion is supported by the occurrence in the East Hyde borehole of the ostracod *Scottia browniana* (Roe, 1999; subsequently confirmed by JW in Wenban-Smith et al., 2007a). It is not known from post-MIS 11 sediments (Whittaker and Horne, 2009). It is also supported by the presence of a 'Rhenish' molluscan fauna from both this deposit and that sampled at Bradwell Hall, suggesting that they are equivalent sequences (Table 4).

4.2 OSL dates

All the samples that were OSL dated showed good luminescence characteristics and good behaviour of the SAR protocol. Thermal transfer was very low and recycling ratios were close to 1 (Table 6). In addition, decay curves from all samples had a significant measurable natural signal compared with the background. They also decayed rapidly, suggesting that the signal being measured was mostly a rapidly bleachable fast component. Equivalent doses were determined on the basis of all 6 aliquots measured, because although there was some scatter, most aliquots fell within 2 standard deviations from the mean (Figure 3). The exception to this was sample

CG05-03 (X2461), where one aliquot yielded a D_e of c. 4000 Gy and was excluded from the dataset before calculation of the mean (Figure 3k).

Despite the seemingly good behaviour of the SAR protocol on these samples, the age estimates discussed below should be considered as initial age estimates only because of the limited number of aliquots used (6) compared with the 50 recently recommended by Rodnight et al. (2006). An approach used here that might mitigate this problem somewhat is that small aliquots were measured, in line with the recommendations of Olley et al. (1999) for potentially partially-bleached sediments. In large aliquots using the full 1 cm diameter of the disc c. 1000 grains are measured from each aliquot (grain size of 150 μm – Wallinga, 2002). In contrast, in this study grains occupied only a 2 mm diameter section of the disc and thus yielded c. 200 grains per aliquot. The use of large aliquots can mask inter-grain variability due to averaging across the aliquot. This might lead to greater age agreement between aliquots and give a false impression of homogeneity. In comparison, the signal measured from small aliquots comes from fewer grains. Thus, averaging within an aliquot is less, each aliquot is more likely to give an extreme value and true variability within the population is more likely to be detected despite limited aliquot numbers (cf. Olley et al., 1998, 1999).

Figure 3 here

Figure 4 here

The reliability of the OSL dates can also be assessed on a stratigraphic basis. Firstly, comparing the replication of ages from single sedimentary units suggests that where multiple age estimates overlap within errors they are broadly reliable. Secondly, regional stratigraphic relationships such as terrace sequences can be used, but only to give depositional order, since the amount of time elapsed between deposition of successive terrace deposits is never known for certain. Thirdly, local direct stratigraphic relationships can be used. This approach is possible in this region because AAR data have also been obtained from the channel fills and direct stratigraphic relationships occur between some channel and gravel deposits.

Testing the robustness of dates using replication of ages between different samples from the same unit is difficult for these samples because of the limited number of aliquots used. However, despite this caveat, these initial age estimates replicate well from Barling Gravel Pit, Doggett's Farm and three from four of the samples from Cudmore Grove (Figure 4, Table 6). The two OSL samples from Burnham Wick Farm do not agree (Figure 4, Table 6). In this case, it seems likely that BURN05-01 (X2455) is too young because the dose rate used was too high. The sample came from a 25 cm thick sand bed surrounded by gravel (Table 3), but the dose rate used was based on the sand only. Had the dose rate included the gravel beds above and below, it would have been lower, leading to an older age estimate. This sample has therefore been excluded from the data used for final age suggestions (Table 7).

Three from four of the samples from the Cudmore Grove Gravel at Cudmore Grove (Table 3) agree within errors (Figure 4, Table 6). AAR and biostratigraphic considerations suggest that the underlying channel deposits were deposited during MIS 9 (Roe et al., 2009). On this basis, the age estimates from CG05-01, -02 and -03 (X2459, X2460, X2461) seem most likely to represent the true age of the deposit. The age estimate from CG05-05 (X2463) is considerably younger. However, this bed is only just above the underlying clay deposits and characterised by considerable, laterally variable, clay content derived from erosion of these (Table 3). It is likely that this has made the environmental dose rate hard to estimate accurately. Clays usually have higher dose rates than sands. If there is higher clay content in the sample measured for environmental dose rate than in the sand surrounding the sample as a whole the measured dose rate will be higher than that actually experienced by the sample and the age therefore underestimated. Furthermore, there is evidence for clay diapirism and periglacial disturbance at the base of the gravels (Roe et al., 2009). This may further complicate age estimation by changing the sedimentary context and therefore dose rate during the period of burial. Without *in situ* gamma spectrometry, which was not possible in this study, it is not possible to clarify further but this sample has been excluded from the data used for final age suggestions (Table 7). This is an example where the use of two age determination techniques and knowledge of local stratigraphic relationships helps to increase the robustness of an age estimate.

Another location where the OSL sample can be assessed in relation to the local stratigraphy is the gravel at the base of Rochford Channel deposits at Apton Hall Farm (APHF05-01, X3080). In this case, this sample was overlain by interglacial clays with an AAR ratio that supports an MIS 9 correlation (Figure 2). This age is also suggested on biostratigraphic grounds based on a sequence from a borehole at Canewdon 1.5 km to the west (Roe, 1994; Roe and Preece, in press). The age estimate from this sample is older than the age inferred for the interglacial deposit, suggesting that it is likely to be reliable. It is, however, surprisingly old, dating from MIS 12-11 rather than MIS 10 which immediately pre-dated the channel infill. This is probably because of problems in environmental dose rate determination of material from boreholes (cf. Bates et al., 2010). The sample was taken from the centre of the first sampling tube to penetrate the gravel at the base of the channel (Table 3). This tube was 40 cm in length, and OSL samples receive environmental dose from a sphere with a diameter of 60 cm, a larger area than it was possible to sample. In addition, the sample was opened in red light to avoid contamination, so any subtle differences in sediment type could not have been detected at this stage. The environmental dose rate used is based on the Uranium, Thorium and Potassium content of the sand sampled for dating only. If it were underestimating the true dose rate received during burial (for example if a higher dose material such as the overlying silt were within a 30 cm radius, as seems likely), then the age estimate obtained would be an overestimate. Because of this uncertainty, it seems safest to say merely that this OSL age estimate does not contradict the suggestion from the AAR that the Rochford Channel deposit dates to MIS 9, but neither does it preclude an MIS 11 age for the Rochford Channel. This sample has therefore been excluded from the data used for final age suggestions (Table 7).

Initial OSL assessments based on those ages accepted as reliable in the discussion above therefore place the age of the Cudmore Grove Gravel at 378–254 ka (MIS 11-8); the Rochford Gravel at Doggetts Farm to 321 – 229 ka (MIS 9–7d); the Dammer Wick Gravel to 213-160 ka (MIS 7c-6) and the Barling Gravel at Barling Gravel Pit to 206 – 106 ka (MIS 7a-5d) (Table 7).

4.3 Thin section analysis

Investigation of a cliff section (S1, TQ 87955 85150) and adjacent borehole (BH1, TQ 87964 85163) at Southend uncovered a fine sand deposit with some silt (Table 3, Figure 5) which might have been part of a Southend Channel (cf. Whitaker, 1889; Bridgland, 1988, 1994; Bridgland et al., 2001) infill. These were targeted for investigation because although this Channel deposit had been described, it had never been sampled. The location of the investigations was based on the location presented by Bridgland et al. (2001) and on discussions with DRB (personal communication, 2005). These deposits span c. 20.8 to 26.3 m O.D. In BH1 they were observed to overlie a thin (80 cm) seam of gravel at an approximate height of 20 to 20.8 m O.D. This may be equivalent to the Southchurch Gravel (Table 3). This gravel then overlay a stiff silty clay thought to be the London Clay. The main spread of the Southchurch Gravel lies to the east of this deposit. No fossil material was recovered from this deposit but a thin section sample was collected from the cliff section (Figure 5) in order to analyse the microstructure for sedimentary features diagnostic of the depositional environment.

Figure 5 here

The thin section, sample SS05(3), was taken across the boundary of two units (Figure 5). The lower unit is characterised by an ice lensing fabric (Figure 5a), formed by sediment and water segregation during freezing and thawing, and indicating that the sediment was within 2 m of the ground surface (Van Vliet-Lanoë, 1991; Van Vliet-Lanoë et al., 1984). This unit also contains clusters of aggregates (Figure 5b), which indicate gelifluction during periods of melt (Van Vliet-Lanoë et al., 1984). The presence of clay skin (argillan) aggregates towards the top of the lower unit (Figure 5c) also indicates gelifluction and re-deposition of sediments. The argillans would originally have been deposited by percolating water to form linings on the insides of pores or coatings on the outside of grains. They commonly form in extremely cold environments where clays disperse easily due to the high dielectric property of meltwater (Van Vliet-Lanoë et al., 1984; van der Meer et al., 1992). The argillans were subsequently mobilised, rounded into aggregates and re-deposited. At the top of the lower unit there is a sharp undulating erosive surface. Clay coatings on aggregates and sand grains overlying this boundary indicate continued (or repeated) periglacial activity (Figure 5d). Unfortunately the periglacial activity has destroyed any original depositional structures the sediment might have contained. Only the texture, clay to medium sand, with sub-rounded or rounded grains, indicates fluvial or aeolian deposition. The undulating erosive boundary between the upper and lower units may result from turbulent fluvial erosion, but this is not definitive; it may also have resulted from slope processes such as gelifluction or debris flow. The status of the Southend Channel is therefore not clear, although these deposits may represent a degraded remnant of it.

5. Timing of deposition of major sedimentary bodies

The dating and thin section results described raise some interesting issues that will be discussed in relation to the stratigraphy, from the oldest to youngest (Table 7).

Table 7 here

5.1 Southchurch / Asheldham Gravels

It is certain that the Southchurch and Asheldham Gravels post-date the diversion of the Thames in the late Anglian, because they are the first Low-level East Essex gravels with a combined Thames-Medway clast lithological signature (Bridgland, 1988; 2003). Gibbard et al. (1996) suggest the Asheldham Gravel immediately post-dates this event and was deposited while a large ice-sheet still existed in the North Sea. This is on the basis of sedimentological characteristics suggesting that it contains deltaic facies feeding into an Anglian pro-glacial lake. Bridgland (2006, Table 2) proposes an interpretation in which all deposits are entirely fluvial in origin and there is a three part sequence. His Asheldham Lower Gravel (attributed by him to MIS 12) is altitudinally lowest, seen in the low altitude of their upper surface (c. 4 m O.D.) in the Bradwell area. The Tillingham Clay is then deposited in a channel form cut into slightly higher elevation gravels (top surface at c. 10 – 15 m O.D., base at c. 5 to 10 m O.D.) c. 3 km to the south-west at Bradwell Hall. This is attributed to MIS 11, which is consistent with AAR data from this deposit at both Bradwell Hall and East Hyde (Figure 2, Table 7). An Asheldham Upper Gravel (attributed by Bridgland to MIS 10) is then described, best developed in the southern part of the Dengie Peninsula near Southminster, where the top surface reaches c. 25 m O.D. and the base mostly between 15 and 20 m O.D. On the Southend peninsula, the Southchurch Gravel is attributed by Bridgland (2006) to MIS 10 only, overlying interglacial deposits within the Southend Channel attributed to MIS 11. However, it should be noted that if the deposits described in this paper from Southend cliff are from Southend Channel deposits, there is no evidence of an overlying gravel here (Table 3, Figure 5).

The archaeological contents of the Southchurch / Asheldham Gravel seem most consistent with a suggestion that neither deposit pre-dates the late temperate phase of the Hoxnian (Ho III) – i.e. that they date from mid MIS 11 or MIS 10. The Asheldham Gravel between Burnham-on-Crouch and Southminster has yielded a number of handaxes, particularly from the site of Goldsands Road (TQ 951 988, Figure 1) where two handaxes were recovered in situ (Wymer 1985: 329). These finds may suggest, by analogy with the Swanscombe sequence, that this gravel is no older than early MIS 11, Ho III. The Southchurch Gravel near Southend has produced reasonably abundant (though poorly provenanced) finds comprising a number of quite fresh condition handaxes, mostly cordate / ovate and one sub-cordate (Wymer 1985; Wessex Archaeology 1996; Wenban-Smith et al., 2007a). The abundance of handaxe finds suggests, again by comparison with the Swanscombe sequence, that the gravel is unlikely to be earlier than the first part of the Hoxnian (MIS 11). This is consistent with Bridgland's (2006) suggestion that the Asheldham Upper Gravel near Southminster and the Southchurch Gravel both date from MIS 10.

The attribution of the Southchurch and Asheldham Gravels to MIS 10 also fits well with evidence from within the Tillingham Channel. Palynological investigation of the Tillingham Channel places these deposits towards the end of the interglacial in the late temperate substage (HoIII - Roe, 2001), postdating Clactonian industries and contemporary with Acheulian industries at Swanscombe (Ashton et al., 2008, but cf. Schreve, 2001). The Tillingham Channel deposits also post-date Clactonian industries at Clacton, where these are found within the pre- and early-temperate substages (Ho I and II) recorded in the freshwater beds (Wymer, 1968). The application of new OSL-dating protocols for older sediments would be valuable to clarify the age of different parts of these deposits. (OSL samples were taken but not analysed during the MVPP project from the Southchurch Gravel in the north of the Southend Peninsula at Saltings, Bridgland's Asheldham Upper Gravel at Asheldham Quarry and possible Asheldham Lower Gravel at Bradwell Hall [Wenban-Smith et al., 2007a, Appendix 4]).

In summary, therefore, It seems most likely that the Asheldham Gravel between Southminster and Burnham-on-Crouch (Bridgland's 2006 Asheldham Upper Gravel) and the Southchurch Gravel near Southend these were deposited during MIS 10.

Presumably the Asheldham Lower Gravel in the Bradwell area dates from MIS 12, but there is no evidence of any type from this deposit.

5.2 High-level channel deposits

In relation to the high-level channel deposits, whilst a channel form clearly exists in the Southend area (Roe, 1994; Roe and Preece, in press), we found no definite evidence for a fossiliferous Southend Channel deposit. Fine-grained deposits were recovered from the area identified as Southend Channel by Bridgland et al. (2001), but these lacked fossils (Table 3). Furthermore, thin section analysis showed that the deposits had been so altered by periglacial activity that it was impossible to determine the original depositional environment. OSL samples were taken but not analysed from this deposit at Southend (SS05 S1, Table 3, Wenban-Smith et al., 2007a, Appendix 4). In future it might be possible to date these using new protocols for older sediments.

As discussed above, AAR ratios from the Tillingham / East Hyde Channel confirmed previous interpretations of the age of this deposit, with opercula from archive material from Roe's (2001) East Hyde borehole and MVPP test pits at Bradwell Hall both yielding ratios consistent with an MIS 11 age (Figure 2, Table 7). This is also supported by the presence of the ostracod *Scottia browniana* at East Hyde which is not known after MIS 11 (Whittaker and Horne, 2009). Test pit stratigraphy at Bradwell Hall also sheds some additional light on the stratigraphic context of the Tillingham / East Hyde Channel infill. As discussed above, Bridgland (2003, 2006) suggests that it is emplaced between a two-part Asheldham Gravel, though without an overlying gravel in the Tillingham / Bradwell area. In contrast, Gibbard et al. (1996) argue that the Tillingham Channel was incised into the Asheldham Gravel and only overlain by a thin veneer of 'fine-grained' gravel which they attribute to a small local stream, although Gibbard (1999) and Roe (2001, and Preece, in press) do refer to an Asheldham Gravel overlying the Tillingham Clay. Test pit investigations at Bradwell Hall in the MVPP showed no gravel overlying the Tillingham Channel deposits in test pit 7 at Bradwell Hall (Figure 6). It did appear to be present adjacent to Tillingham Channel deposits at Bradwell Hall, in test pits 2 and 5 (Figure 6; Wenban-Smith et al., 2007a). Between these test pits, London Clay bedrock was exposed at the surface. The status of the gravel in these test pits is, however, unclear. Again, OSL samples are available from this deposit (Wenban-Smith et al., 2007a, Appendix 4), dating of which in future using new protocols might shed light on the stratigraphic disputes in this area, although the error bars generated might still be too large.

Figure 6 here

5.3 Intermediate level deposits in the Rochford area

The most problematic units in the eastern Essex succession are the Rochford Gravel, Rochford Channel and Rochford Channel Gravel because of their intermediate elevation between the Southchurch and Barling Gravels. Bridgland (et al., 1993; Table 1) reassigned the Rochford Gravel as an extension of the Southchurch Gravel, attributing their lower elevation to surface erosion. In this model the Rochford Channel was cut into the Southchurch Gravel, and the Rochford Gravel interpreted as the upper part of a gravel-silt-gravel 'sandwich' within the Southchurch Gravel. In contrast, Bridgland (2003, 2006) shows deposits in this area as Barling Gravel, despite showing in his 2006 transverse section that Rochford Channel deposits are mostly exposed at the surface, with limited overlying gravel.

Figure 7 here

These contrasting interpretations are indicative of the complexity associated with these deposits in the Rochford area. Examination of the borehole records (Figure 7) shows that the bulk of the Rochford area deposits are channel deposits. Gravel is recorded with an upper surface at c. 10-11 m O.D. in boreholes in the inside loop of the Rochford Channel (including the OSL-dated site at Doggetts Farm, Figure 1). This is adjacent to and has an upper surface altitudinally lower than the Rochford Channel deposits (at c. 5 to 15 m O.D.), with no direct relationship to them, but significantly higher than the Barling Gravel at c. 0 to 5 m O.D. in this area (Figure 7). A second gravel also occurs as thin layers (< 1 m) of fluvial gravel overlying the Rochford Channel in places with a top surface at c. 12 to 15 m O.D. (Figure 7). It should be noted that there is no mapped equivalent of this gravel body intermediate between the Asheldham and Dammer Wick Gravels on the Dengie Peninsula, although the Asheldham Gravel spans a wide altitudinal range. For example, near Bradwell power station, at the tip of the peninsula, the upper surface of this gravel body is considerably altitudinally lower than the Asheldham Gravel elsewhere on the peninsula (c. 4 m O.D. cf. c. 25 m O.D., Wenban-Smith et al., 2007a). It is possible that this correlates with the Rochford Gravel, although Bridgland (2006) attributes it to an eroded remnant of his Asheldham Lower Gravel.

Our dating of these deposits (Table 7) suggests a correlation of the Channel deposits themselves with MIS 9 and the Rochford Gravel at Doggett's Farm sometime between MIS 9-7d (321-229 ka, Table 7). These are broadly in stratigraphic order and confirm Bridgland et al. (2001)'s and Roe and Preece's (in press) attribution of the Rochford Channel to MIS 9. In terms of their relationship to the ages from altitudinally lower deposits further east, both the Doggett's Farm dates predate the ages from the Barling and Dammer Wick Gravels (see below). It is possible that this gravel represents a marginal deposit associated with the Barling Gravel, predating a final incision and deposition event that is recorded further east at Barling and Shoeburyness. Given the small number of aliquots and preliminary nature of these OSL dates, there is still a small possibility that this gravel is an eroded remnant of the Southchurch Gravel as argued by Roe (1994) and Bridgland et al. (1993), but this seems unlikely. The MIS 8 age estimate for this gravel deposit is younger than any of the ages suggested by previous authors, who suggested that it dated from MIS 12 (Bridgland, 2003), or MIS 12 or 10 (Roe and Preece, in press).

5.4 Low-level channel deposits

Figure 8 here

AAR results place the deposition of the Shoeburyness Clay into MIS 9 (Roe et al., 2011, Table 7). This is the same interglacial as the Rochford Channel and somewhat surprising because the Shoeburyness Channel is considerably lower lying than the Rochford Channel (c. -7 to 3 m O.D. cf. c. 5 to 15 m O.D.), which is often taken as an indicator of younger deposition. There are a number of possible explanations for this altitudinal difference. Bridgland (2006) attributes it to abandonment of the channel before completion of downcutting, with the deepest downcutting at Shoeburyness. However, drawing analogies with modern day estuaries, it is possible for channels within the same estuary to have bases at very different levels. This reflects the large bathymetric range in an estuary in contrast to fluvial systems. Roe and Preece (in press) note that locally within the Burnham Channel near Dammer Wick there appears to be no basal gravel present. It therefore seems most likely that the Rochford Channel was only part of a channel whose main flow was in the Shoeburyness area.

Roe's borehole at Canewdon (Figure 8; Roe, 1994; 1999; and Preece, in press) contains faunas of a marginal tidal backwater with some freshwater inputs in the early stages of deposition. Our borehole at Apton Hall Farm contains *Bithynia tentaculata* opercula. This may indicate greater freshwater influence in this sequence, although the microfossils are more brackish (JW in Wenban-Smith et al., 2007a). The upper part contained ostracods of low diversity but typical of tidal rivers. This was indicative of brackish water (salinity of > 5 ppt), perhaps a backwater away from the main river. The occurrence of foraminifera in the uppermost sample indicates this may not have been far from the estuary mouth at the time. More freshwater molluscs were also reported from the Rochford Clay by Lake et al. (1977) in a different borehole. It is therefore possible that the fossil content of this deposit is spatially variable.

Roe (1994, 1999; Roe and Preece, in press) also investigated the Burnham Channel at North Wick, with a borehole that reached 15 m below ground level. Redrilling at North Wick Farm in the MVPP project reached depths of 21 m below ground level but still did not yield material suitable for AAR dating. Ostracod faunas recovered were very similar to those from the original borehole (NW1), with the exception of specimens of *Cytherissa lacustris* found near the base of the drilled sequence. This species prefers cool, deep, freshwater environments and its presence at the base of the sequence is consistent with a general increase in salinity towards the top of the sequence. This increase in salinity is also seen in the occurrence of small calcareous foraminifera at the top of the sequence. Foraminifera such as these in tidal rivers usually suggest proximity to the estuary mouth (JW in Wenban-Smith et al., 2007a). It is possible that freshwater deposits and the base of the channel are only just below the base of the sequence drilled in the MVPP project, particularly since lumps of reworked London Clay were found in these deposits (Wenban-Smith et al., 2007a). This difficulty in recovering freshwater deposits is consistent with the pattern observed in the other low-level Essex channels (Shoeburyness, Cudmore Grove), where the marine transgression occurs in the 'pre-temperate' or 'early temperate' substages of the interglacial (Roe et al., 2009, in press, Figure 8).

In the absence of AAR data or biostratigraphically significant species, the age of the Burnham Clay can only be inferred in relation to other channel deposits. It is possible that it is continuous with the East Wick Channel further east. AAR evidence suggests that the East Wick Channel was deposited during MIS 9 and the presence of *Corbicula fluminalis* (Table 4) suggests that it is pre-Ipswichian. Borehole data (Figure 9) and bedrock contours plotted by Lake et al. (1977) might suggest that the two deposits are continuous. However, more recent analysis of bedrock contours (Roe, 1994; and Preece, in press) show that the deposits at East Wick occur within a deep bedrock depression whose origin is unclear. Despite these difficulties, the balance of probabilities place deposition of the Burnham Clay into MIS 9 (Bridgland, 2003, 2006; Roe and Preece, in press).

Figure 9 here

5.5 Barling / Dammer Wick Gravels

The Barling Gravel at Barling Gravel Pit has been dated to MIS 7a-5d by the initial OSL dating presented in this paper (Table 6, Figure 4) and the Dammer Wick Gravel at Burnham Wick Farm to MIS 7c-6. These are the first of the OSL ages presented in this paper that conflict significantly with established age estimates. (There is also a conflict with the Rochford Gravel, but all authors recognise the complexity of this area and the provisional nature of their age estimates). Bridgland has consistently (1988, 2003, 2006) correlated the Barling Gravel with MIS 8 based both on the fact that it directly overlies channel deposits laid down during MIS 9 at both Barling (Bridgland et al., 2001) and Shoeburyness (Roe, 1994; 1999) and on the basis of downstream correlation with the Thames sequence (Bridgland et al., 1993). This latter line of evidence suggests that during MIS 6, gravels were being deposited noticeably further east and at lower altitudes beneath Foulness Island (Figure 1). A further line of evidence is the numerous handaxes, many in fresh condition, that have been found within this gravel, particularly at Baldwin's Farm (Wymer, 1985; Wessex Archaeology, 1996). If one regards this evidence as reflecting occupation contemporary with the Barling Gravel, then accepting an MIS 6 age would suggest occupation in eastern Essex during a period when Britain, and indeed northwestern Europe as a whole, is widely presumed to be deserted (eg. Ashton and Lewis 2002; Hublin and Roebroeks 2009). Furthermore, MIS 6 would be an unusually late period for handaxe-dominated lithic technology to be predominant. One Levallois artefact is reported from this gravel, from Martin's Gravel Pit at Great Stambridge, but this is not securely provenanced.

Given this discordant information, it is worth thinking a little more about the reliability of these OSL ages. It should be noted first that all three dates from Barling agree well, both with each other, and with the date that has been accepted as reliable (BURN05-02, X2457) from the correlative Dammer Wick Gravel at Burnham Wick Farm (Figure 4, Table 7). Furthermore, the SAR protocol behaved well for all aliquots, although the limited number of aliquots probably means that the full range of variation in equivalent doses has not been captured. Thus these ages are preliminary only. To further complicate matters, a handaxe was found during MVPP fieldwork at Barling Gravel Pit (Table 3, Wenban-Smith et al., 2007a).

There seem to be two possible explanations for this conflict in interpretation. Firstly, it is possible that these initial OSL ages are too young and that measurement of more aliquots would give an older age. However, the agreement between samples so far is striking and significant differences in equivalent doses from subsequent aliquots would be required to increase the ages to be consistent with MIS 8.

Secondly, the locations sampled for OSL dating potentially do not fall within the deposits originally mapped by Bridgland. This seems likely at Barling where section BLNG-05-S1 (Table 3) lies c. 1 km from the sections in Barling Hall Pit described and sampled by Bridgland et al. (2001) and outside their mapped Barling Gravel limits (Figure 1). Furthermore it is lower by c.10 m (top at c. -7 m O.D.) than both Barling Gravel occurrences recorded in the boreholes shown (Figure 7) and also exposures in Barling Hall Pit, which overlie London Clay at +1-2m OD (Bridgland et al., 2001). The gravels recorded in BLNG-05 may therefore be unrelated to the Barling Gravel. In this interpretation, the handaxe found during MVPP fieldwork would be presumed to be reworked. A misidentification of deposits seems less likely at Burnham Wick Farm, where the top of the gravels falls at c. 1.5 m (Table 3) compared with other occurrences in boreholes at c. 4 m O.D. (Figure 9). Even here though, it is a possible explanation.

It is not possible at the moment to state which of these explanations is more likely. Neither can we comment conclusively on the potential age of this deposit.

5.6 Mersea Island deposits

There are two gravel deposits recognised on Mersea Island – Cudmore Grove Gravel and Mersea Island Gravel (Bridgland and Sutcliffe, 1995; Roe and Preece, in press, Figure 1, Table 2). The Cudmore Grove Gravel immediately overlying the Cudmore Grove Channel has been OSL dated in this project. Ages from three of the four samples place the deposition of the Cudmore Grove Gravel broadly in MIS 8, which fits well with the inferred MIS 9 age assigned to the underlying channel deposits (Roe et al., 2009). The single age estimate that is younger (CG05-05, X2463) is believed to have an overly high dose rate and thus underestimated age due to proximity to the underlying interglacial clays (Table 3). These problems are not seen in the other samples from this site, which were higher above the sedimentary boundary (Table 3).

Further insights into the age of deposits on Mersea Island are provided by AAR data from opercula from the East Mersea Restaurant Site. Opercula yield an AAR value that suggests an age of MIS 5e, which is consistent with the vertebrate evidence previously discussed. Multiple channels with similar heights and different ages have also been noted on the south coast (e.g. Preece et al., 1990; Bates and Briant, 2009; Bates et al., 2009).

6. Conclusion

The research reported in this paper has shown the potential of integrating two dating techniques in suggesting ages for deposits. Where samples were taken from gravels and channel deposits from the same stratigraphic sequence, i.e. at Cudmore Grove and Apton Hall Farm, they have been found to be in the correct stratigraphic order, and to suggest sensible respective ages. Use of multiple techniques is important because each has different strengths and weaknesses. As discussed above, the AAR technique has the limitation that less racemisation occurs within glacial periods, causing ratios to overlap from successive interglacials (e.g. Miller et al., 1999; McCarroll, 2002; Penkman et al., 2008b, in press). Whilst this overlap is less pronounced when analysing calcitic opercula, it is still necessary to also take into account palaeoenvironmental and biostratigraphic evidence. In contrast, OSL dating provides numerical age estimates, but requires significant resources to measure sufficient aliquots to ensure robustness, particularly at older ages.

The main limitations of OSL dating observed in this study are twofold. Firstly, a large number of aliquots are needed to generate a representative equivalent dose distribution from fluvial sediments (Rodnight et al., 2006), but this is hard to achieve for older samples which take a long time to measure. This was mitigated in part in this study by the use of small aliquots (which increases the detection of scatter) and the inclusion of all aliquots within two standard deviations of the mean in the final age determination. Nonetheless, it is possible that an important part of the equivalent dose distribution has not been captured in this data. Secondly, there are difficulties with correctly estimating environmental dose rates where the sand bed sampled is less than 60 cm thick, or where sediments are non-homogeneous within a 30 cm radius, as at Cudmore Grove and also within boreholes, where inhomogeneity cannot be detected. The presence of an additional method of age estimation can be valuable, as seen in the discussion of dates from Cudmore Grove. In this case, the attribution of the interglacial clays to MIS 9 using AAR (Roe et al., 2009) reinforced evidence from the luminescence behaviour of the OSL samples suggesting that CG05-05 (X2463) had yielded an age estimate that was too young.

The dating of these complex deposits from eastern Essex has a number of stratigraphic implications. Firstly, the suggested ages for those channel deposits from which palaeontological and palaeobotanical work has been undertaken are reinforced, suggesting that the 'high-level' channels in this region date from MIS 11, as previously suggested by Bridgland (1988, 2003) and Roe (2001), and that the intermediate Rochford Channel and the 'low-level' channels all date from MIS 9, as suggested by Roe et al. (2009; 2011, and Preece, in press) and Bridgland et al. (2001).

The evidence for age of the gravels from OSL dating must be seen as preliminary, since a limited number of aliquots were measured. More importantly, it is not clear that the age estimates of MIS 6 from the Barling Gravel came from the main spread of gravel previously identified (see discussion above). Further investigation of these deposits is required. Archaeological evidence from the Southend and Dengie peninsulas suggests that previous attribution of these gravel deposits to MIS 10 seems reasonable, although the limits of the OSL technique mean that they cannot be directly dated. Follow-on work using newly-developed OSL protocols for older sediments would be useful from these deposits, especially since samples have already been taken.

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Reference:	Southend Peninsula	Dengie Peninsula	Mersea Island	Clacton
Bridgland (1983a,b)	Submerged terraces x 3 Barling Gravel / Shoeburyness Channel Rochford Gravel / Rochford Channel Southchurch Gravel / Southend Channel	Submerged terraces x 3 Dammer Wick Gravel Marsh Road Gravel Asheldham Gravel / Burnham Channel		
Bridgland (1988)	Submerged terraces x 3 Barling Gravel Shoeburyness Channel Rochford Gravel Rochford Channel Southchurch Gravel / Southend Channel	Submerged terraces x 3 Dammer Wick Gravel Burnham Channel Asheldham Gravel / Tillingham Channel	Mersea Island Gravel, including Cudmore Grove Channel	Wigborough Gravel Wigborough Gravel, including Clacton Channel
Roe (1994); Bridgland et al. (1993)	Submerged terraces x 3 Barling Gravel Southchurch Gravel[1]			
Gibbard (1999) [2]	Shepperton Member (offshore) Barling Member Asheldham Member (Gibbard *et al.*, 1996 – fluvial, deltaic, lacustrine facies; Bridgland, 1994, 1995 – fluvial facies)		Shepperton Member (offshore) Barling Member Mersea Island Member Holland Member	
Bridgland (2003)	Submerged terraces equivalent to Lower Thames Shepperton, East Tilbury Marshes and Mucking Gravels Barling Gravel Shoeburyness Channel (including gravel) Southchurch Gravel Southend Channel (including gravel) ? Rochford Gravel	Not listed or mapped separately	Not listed or mapped separately	Wigborough Gravel Clacton Channel Holland Gravel

Table 1: Previous stratigraphic nomenclature and suggested correlations of the low-level (i.e. post-diversion) eastern Essex gravels and associated channel fills. Youngest deposits are at the top of each list. [1]Gravel previously mapped as Rochford Gravel reassigned to a dissected Southchurch Gravel spread. [2]Scheme does not appear to designate all the submerged gravel deposits recognised by Bridgland *et al.* (1993).

Middle Thames	Lower Thames	Southend Peninsula	Dengie Peninsula	Mersea Island / Tendring Peninsula	Climate	Stage	MIS
Taplow	Mucking	Submerged gravels beneath Holocene alluvium on Foulness / Havengore Island	*unknown*	Within Cudmore Grove Gravel[2]? *(tributary: proto-Blackwater or Colne)*[3]	cold	'Saalian'	6
	Aveley interglacial deposits	*unknown*	*unknown*	*unknown*	warm	'Intra-Saalian' interglacial	7
Lynch Hill	Corbets-Tey	Barling Gravel	Dammer Wick Gravel	Within Cudmore Grove Gravel[2] *(tributary: proto-Blackwater or Colne)*[3]	cold	'Saalian'	8
	Purfleet-Grays interglacial deposits	'Shoeburyness Clay' / 'Rochford Clay'	'Burnham Clay'	Cudmore Grove Channel interglacial beds	warm	'Intra-Saalian'? interglacial	9
		'Shoeburyness / Rochford Channel Gravel'	'Burnham Channel Gravel'	'Cudmore Grove Channel Gravel'	cold?	'Saalian?'	
Boyn Hill	Orsett Heath	Within Southchurch Gravel	Within Asheldham Gravel	Mersea Island Gravel / Wigborough	cold	'Saalian?'	10
		'Rochford Gravel' (*erosional remnant*)?	(='Asheldham Upper Gravel'[1])	Gravel (part)			
	Swanscombe interglacial deposits	Southend Channel interglacial deposits?	'Tillingham Clay'	Clacton Channel interglacial deposits	warm	Hoxnian	11
Black Park	Age of possible aggradations	Within Southchurch Gravel	Within Asheldham Gravel	Within Mersea Island / Wigborough	cold	late Anglian	12
		'Rochford Gravel' (*erosional remnant*)?	(='Asheldham Lower Gravel'[1])	Gravel			
Diversion of the Thames--*stratigraphic marker*---					cold	Anglian	12

Table 2: Integrated gravel / channel stratigraphy for eastern Essex and correlations with the Thames sequence suggested by Roe and Preece (in press). [1] Bridgland (2006); [2] Bridgland and Sutcliffe (1995); [3] Roe et al. (2009).

Context number and depth below ground surface (m)	Sediment description	Stratigraphic attribution	Samples reported in this paper
Southend peninsula			
Barling Gravel Pit S1 (Barling Gravel) – 593825 190650, -8.36 m O.D. (N.B. lower part of quarry succession)			
10 – 0-0.92	Cross-bedded sand grading upwards into horizontally-bedded gravel	Barling Gravel	
11 – 0.92-1.04	Fine sand and silt grading upwards into a medium sand.	Barling Gravel	
12 – 1.04-2.06	Cross-bedded sand with 5 cm gravel at base and fine gravel along bedding planes in upper 65 cm.	Barling Gravel	OSL: BLNG05-01 (1.73 m below top of face)
13 – 2-2.18	Medium brown silty clay with fine sand.	Barling Gravel	
14 – 2.18-2.54	Medium sand with ripple laminations in lower 30 cm and cross-bedding above.	Barling Gravel	OSL: BLNG05-03 (2.27 m below top of face)
15 – 2.54-3.18	Cross-bedded sandy gravel.	Barling Gravel	
16 – 3.18-4.2	Multiple cross-bedded lenses of gravelly sand containing bone material.	Barling Gravel	
17 – 4.2-4.6	Horizontally-bedded and cross-bedded lenses of medium sand with some pebbles.	Barling Gravel	OSL: BLNG05-05 (4.65 m below top of face)
18 – 4.6-5.06	Horizontally-bedded gravel with grey brown organic silty clay drapes with shell and plant material.	Barling Gravel	
19 – 5.06-5.22	Medium sand with a 5 cm thick grey brown clay lens containing shell and plant material.	Barling Gravel	
20 – 5.22-6.29	Sand containing pointed handaxe and bone material.	Barling Gravel	
Doggetts Farm TP2 (Rochford Gravel) – 588298 191946, 11.73 m O.D.			
20 – 0-0.5	Brown silty clay topsoil.	Overburden	
21 – 0.5-1.2	Reddish brown silty clay with rare pebbles.	Brickearth	
22 – 1.2-2.6	Very sandy gravel	Rochford Gravel	OSL: DOGF05-02 (1.70 m below ground surface)
Doggetts Farm TP3 (Rochford Gravel) – 588253 191935, 11.7 m O.D.			
30 – 0-0.24	Medium brown topsoil.	Overburden	
31 – 0.24-0.8	Reddish brown silty clay with rare pebbles.	Brickearth	
32 – 0.8-0.9	Very sandy gravel with clay	Poorly sorted ‘head’	
33 – 0.9-2.3	Very sandy gravel with massive medium sand bed in top 16 cm and clay-rich matrix from 1.32-1.7.	Rochford Gravel	OSL: DOGF05-03 (0.95 m below ground surface)
Apton Hall Farm BH1 (Rochford Clay) – 588860 193175, 12.68 m O.D.			
0-0.5	Plough soil.	Overburden	
0.5-1.5	Clay with flints.	Poorly sorted ‘head’	
1.5-7.5	Brown grey silty clay.	Rochford Clay	AAR: <BH3A> (5-5.5 m)
7.5-8.5	Greyer sandy silt.	Rochford Clay	
8.5-12	Sands and gravels.	Rochford Channel Gravel	OSL: APHF05-01 (8.5-8.9m)
12-	Stiff grey clay.	London Clay	
Roe’s (1994, 1999) Shoeburyness borehole S1 (Shoeburyness Clay) TQ 93375 85483, 7.04 m O.D.			
0-0.6	Made ground.	Overburden	
0.6-4.7	Yellow-brown gravelly sand.	Barling Gravel	
4.7-8.8	Brown grey sandy clay.	Shoeburyness Clay	
8.8-13.5	Dark grey silty clay with wood fragments.	Shoeburyness Clay	
13.5-14.8	Dark grey sandy silt with shell fragments and stones.	Shoeburyness Clay	AAR: 13.9 and 14.42-14.44

			m
14.8-16.8	Dark grey sandy gravel.	Shoeburyness Channel Gravel	
Southend cliff S1 (?Southend Channel) TQ 87955 85150, 26.32 m O.D.			
0-0.2	Made ground.	Overburden	
0.2-1.56	Dark orange faintly laminated fine to medium sand with horizontal beds of fine to coarse pebbles.	?Southend Channel	
1.56-2.24	Light grey faintly laminated fine sand.	?Southend Channel	Thin Section: SS05 (3) (2.2-2.3 m [at boundary])
2.24-2.4	Dark brown silty clay with weathered white material at upper and lower contacts.	?Southend Channel	
2.4-2.86	Massive mottled light grey / dark orange fine sand / silt.	?Southend Channel	
Southend cliff BH1 (?Southend Channel overlying Southchurch Gravel) TQ 87964 85163, 27.96 m O.D.			
0-1.8	Made ground.	Overburden	
1.8-2.55	Firm mid-brown brickearth.	?Southend Channel	
2.55-4.2	Firm pale brown fine sand.	?Southend Channel	
4.2-4.55	Very stiff brown / grey mottled silty and sandy clay.	?Southend Channel	
4.55-7.2	Fine to coarse sand.	?Southend Channel	
7.2-8	Small to large gravels.	Southchurch Gravel	
8-13.8	Stiff silty clay.	London Clay	
Dengie peninsula			
Kennard's first East Wick borehole – TQ99NE/45B (East Wick channel deposit) – TQ 9995 9646, 3.05 m O.D.			
0-29.0	Unrecorded	East Wick channel deposit	
29.0-32.1	Fine white flint gravel with clay.	East Wick channel deposit	
32.1-41.2	Clay with shells and small pebbles.	East Wick channel deposit	
41.2-	Stiff grey clay	London Clay	
Kennard's second East Wick borehole – TQ99NE/45A (East Wick channel deposit) – TQ 9995 9647, 3.05 m O.D.			
0-1.8	Red clay	Holocene alluvium	
1.8-12.2	Blue clay	Holocene alluvium	
12.2-13.7	Shells	East Wick channel deposit	AAR: 12.2-13.7 m
13.7-20.4	Sand and shells	East Wick channel deposit	
20.4-38.1	Gravel	East Wick Channel Gravel	
38.1-	Stiff grey clay	London Clay	
Kennard's third East Wick borehole – TQ99NE/45D (East Wick channel deposit) – TQ 999 964, 3.05 m O.D.			
0-1.8	Red clay	Holocene alluvium	
1.8-11.6	Blue clay	Holocene alluvium	
11.6-13.1	Shells	East Wick channel deposit	
13.1-20.1	Sand	East Wick channel deposit	
20.1-30.5	Gravel	East Wick Channel Gravel	
30.5-	Stiff grey clay	London Clay	
Burnham Wick Farm TP1 (Dammer Wick Gravel) – 596030 195806, 2.74 m O.D.			
10 – 0-0.3	Plough soil.	Overburden	
11 – 0.3-1.2	Brown silty clay with black manganese flacks and flints in lowest 10 cm.	Overburden	
12 – 1.2-2.2	Sandy gravel containing a 25 cm bed of massive fine sand.	Dammer Wick Gravel	OSL: BURN05-01 (1.7 m below ground surface)

Burnham Wick Farm TP2 (Dammer Wick Gravel) – 596624 195769, 2.09 m O.D.			
20 – 0.-0.3	Plough soil.	Overburden	
21 – 0.3-0.4	Yellowish brown fine sand with rare pebbles.	Overburden	
22 – 0.4-0.9	Brown medium sand grading upwards into silt with abundant gravel.	Overburden	
23 – 0.9-1.35	Reddish brown medium sand with horizontally-bedded dispersed gravel.	Dammer Wick Gravel	OSL: BURN05-03 (1.1 m below ground surface)
24 – 1.35-1.9	Clast-supported gravel.	Dammer Wick Gravel	
25 – 1.9-2	Soft light grey silty clay.	Dammer Wick Gravel	
26 – 2-2.7	Gravel.	Dammer Wick Gravel	
Roe's (1994, 2001) East Hyde borehole EH1 (Tillingham Clay) – TL 9804 0408, 15.7 m O.D.			
0-5.6	Sandy clay-silt with shell fragments at base.	Tillingham Clay	
5.6-8.7	Very dark brown clayey silt with shell fragments in places.	Tillingham Clay	AAR: 7.55 m
8.7-9.6	Silty sand with shell debris.	Tillingham Clay	AAR: 9.2 m
Bradwell Hall TP7 (Tillingham Clay) – 598757 205639, 13.43 m O.D.			
70 - 0-0.2	Sandy topsoil.	Overburden	
71 - 0.2-0.8	Yellowish brown sandy silt.	Tillingham Clay	
72 – 0.8-2.4	Brown sandy silt with occasional fine flints, abundant molluscs, rare small vertebrates and race nodules.	Tillingham Clay	AAR: <13>
73 – 2.4-2.5	Fine sandy clay with shell lamina.	Tillingham Clay	
74 – 2.5-2.8	Brown sandy silt with molluscs.	Tillingham Clay	
75 – 2.8-2.9	Sandy gravel with shells.	Tillingham Channel Gravel	
Mersea Island			
Bridgland et al.'s (1995) East Mersea Restaurant site TM 053 136, 4.5 m O.D.			
0-1	Brown clayey silt.	-	
1-1.2	Grey sandy silt with bones and shells.	-	AAR: Sample 3
1.2-1.6	Gravel with mammal bones.	Restaurant Gravel	
1.6-	Stiff blue grey clay.	London Clay	
Cudmore Grove S1 (Cudmore Grove Gravel) – 606830 214647, 8.94 m O.D.			
10 – 0-0.45	Gravel-rich topsoil with some bricks.	Overburden	
11 – 0.45-0.9	Fine sand / silt with dispersed pebbles.	Cudmore Grove Gravel	
12 – 0.9-1.6	Horizontally-bedded gravel with sand drapes every c. 10 cm.	Cudmore Grove Gravel	
13 – 1.6-1.85	Trough cross-bedded sand with pebbles along bedding planes.	Cudmore Grove Gravel	
14 – 1.85-2.8	Poorly-sorted gravel with rough cross-bedding within large scour-form. Possible frost crack.	Cudmore Grove Gravel	
15 – 2.8-4.35	Coarse low-angle-bedded sand with pebbles in upper 95 cm and rare silt drapes below.	Cudmore Grove Gravel	OSL: CG05-01,02 (3.95 m below ground surface)
Cudmore Grove S2 (Cudmore Grove Gravel) – 606775 214609, 8.3 m O.D.			
20 – 0-0.5	Massive fine sand / silt with soil in upper 40 cm.	Overburden	
21 – 0.5-1.1	Poorly sorted gravel with stone erection in top 10 – 15 cm.	Cudmore Grove Gravel	
22 – 1.1-1.4	Horizontally-bedded sand with fine gravel along bedding planes.	Cudmore Grove Gravel	
23 – 1.4-2.5	Horizontally-bedded gravel with occasional planar cross-bedded sand lenses c. 10 cm thick.	Cudmore Grove Gravel	
24 – 2.5-3.8	As above, but including some silty clay lenses c. 5-10 cm thick.	Cudmore Grove Gravel	
25 – 3.8-4.1	Light olive grey massive coarse sand with clay and some dispersed pebbles.	Cudmore Grove Gravel	OSL: CG05-03 (3.2 m below

			ground surface) OSL: CG05-05 (3.9 m below ground surface)
26 – 4.1-4.25	Light grey clay with plant beds.	Cudmore Grove Clay	

Table 3: Stratigraphy and sediment description for sequences whose sample results are reported in this paper. East Wick Channel borehole data is based on the comparison of BGS borehole records with unpublished notes by A.S. Kennard at the Natural History Museum. Kennard does not have detailed borehole stratigraphies, but his notes about the nature of the material left as residue at various sample depths have been compared to the sediments recorded in the BGS boreholes and there is a clear relationship between the records, with shell layers recorded at identical depths in each. In addition, these boreholes are known to have been done at the same date as those noted by Kennard and it is therefore assumed that they are the same.

	Shoeburyness, Borehole S1			East Wick boreholes			East Hyde, Borehole EH1					Bradwell Hall, Essex (BRADH 05)				East Mersea Restaurant site, Mersea Island.
	14.6	14.3	13.9	1 - TQ99NE/45B	2 - TQ99NE/45A	3 - TQ99NE/45D	7.52	7.55	7.6	7.72	7.74	<8>	<13>	<15>	<17>	Sample 3
Freshwater taxa																
Theodoxus danubialis	-	-	-	-	-	-	-	1	1			+	+	+	+	
Viviparus diluvianus	-	-	-	-	-	-						+	+	+	+	
Valvata naticina	-	-	-	-	-	-	-					+	+	+	+	
Valvata piscinalis	-	1	?1	-	-	-	-					+	+	+	+	18
Valvata spp.								2	2							
Heleobia sp.	-	-	-	-	-	-						+	+	+	+	
Belgrandia marginata				-	At 15.3-18.3 m depth	-										
Bithynia tentaculata shells	-	-	1	-	-	-	-	1	1			+	+	-	+	2
opercula	3	2	9	At all depths (29-41.2 m)	At 12.2-21.4 and 25.9-29.0 m depths	At 9.2-18.3 m depth	2	7	7	1		+	+	-	+	11
Bithynia troschelii	-	-	-	-	-	-	-					-	+	-	-	
Unionidae																fragments
Sphaerium sp.																9
Lymnaea sp.	-	-	-	-	-	-	1	-	-			+	+	-	-	
Planorbarius corneus																1
Corbicula fluminalis	-	-	-	At all depths (29-41.2 m)	At all depths (12.2-29.0 m), except 19.8-21.4 m	At all depths (9.2-30.5 m)	-	1	1		1	+	+	+	+	
Pisidium amnicum	-	-	-	-	-	-						+	-	+	+	6
Pisidium nitidum				-	-	-	-	1	1							
Pisidium subtruncatum	-	-	-	-	-	-						+	-	-	-	
Pisidium supinum	-	-	1	-	-	-						+	-	-	+	
Pisidium henslowanum	-	-	1	-	-	-						+	-	-	-	27
Pisidium moitessierianum	-	-	-	-	-	-	1	-	-			+	-	-	-	6
Pisidium spp (other)																9
Marine / brackish taxa																
Hydrobia ventrosa				-	-	-	-	-	1							

Hydrobia ulvae																
Hydrobiidae undet.				-	-	-	5	2	4		3					
Cerastoderma glaucum	-	-	-	-	-	-						-	-	-	+	
Cerastoderma sp.																
Terrestrial taxa																
Succineidae				-	-	-										2
Deroceras/Limax				-	-	-										4
Other items																
Small mammals							-	-	-							
Fish scales and teeth							+	+	-							
Ostracods							+	+	+	+	+					
Seeds							-	-	-							

Table 4: Molluscs present in samples submitted for AAR analysis.

NEaar no.	Sample name	Asx D/L	Glx D/L	Ser D/L	Ala D/L	Val D/L	[Ser]/[Ala]
3737bF	APHBto1bF	0.744 ± 0.001	0.383 ± 0.001	0.923 ± 0.033	0.455 ± 0.004	0.264 ± 0.008	0.335 ± 0.000
3737bH*	APHBto1bH*	0.638 ± 0.010	0.273 ± 0.006	0.685 ± 0.008	0.376 ± 0.001	0.203 ± 0.003	0.339 ± 0.004
3738bF	APHBto2bF	0.732 ± 0.002	0.365 ± 0.001	0.926 ± 0.005	0.452 ± 0.004	0.246 ± 0.005	0.426 ± 0.001
3738bH*	APHBto2bH*	0.632 ± 0.002	0.276 ± 0.002	0.684 ± 0.001	0.372 ± 0.004	0.199 ± 0.000	0.429 ± 0.008
3739bF	APHBto3bF	0.729 ± 0.001	0.354 ± 0.005	0.959 ± 0.020	0.428 ± 0.006	0.234 ± 0.004	0.443 ± 0.003
3739bH*	APHBto3bH*	0.630 ± 0.000	0.260 ± 0.003	0.691 ± 0.005	0.358 ± 0.001	0.178 ± 0.001	0.399 ± 0.011
3826bF	APHBto4bF	0.755 ± 0.001	0.387 ± 0.009	0.989 ± 0.015	0.453 ± 0.003	0.258 ± 0.006	0.382 ± 0.020
3826bH*	APHBto4bH*	0.649 ± 0.000	0.268 ± 0.012	0.670 ± 0.013	0.369 ± 0.003	0.184 ± 0.005	0.352 ± 0.007
3827bF	APHBto5bF	0.739 ± 0.004	0.372 ± 0.004	0.997 ± 0.004	0.447 ± 0.008	0.259 ± 0.010	0.441 ± 0.012
3826bH*	APHBto5bH*	0.633 ± 0.000	0.264 ± 0.000	0.681 ± 0.007	0.363 ± 0.000	0.181 ± 0.006	0.384 ± 0.027
3731bF	BHBto1bF	0.750 ± 0.003	0.436 ± 0.002	0.978 ± 0.004	0.463 ± 0.003	0.266 ± 0.003	0.330 ± 0.002
3731bH*	BHBto1bH*	0.681 ± 0.007	0.320 ± 0.000	0.778 ± 0.018	0.427 ± 0.002	0.234 ± 0.004	0.307 ± 0.004
3732bF	BHBto2bF	0.754 ± 0.000	0.373 ± 0.000	0.965 ± 0.003	0.466 ± 0.007	0.264 ± 0.007	0.325 ± 0.004
3732bH*	BHBto2bH*	0.671 ± 0.009	0.294 ± 0.001	0.662 ± 0.017	0.415 ± 0.003	0.217 ± 0.003	0.329 ± 0.004
3733bF	BHBto3bF	0.747 ± 0.007	0.369 ± 0.014	0.856 ± 0.112	0.463 ± 0.007	0.261 ± 0.006	0.392 ± 0.024
3733bH*	BHBto3bH*	0.651 ± 0.002	0.288 ±0.002	0.538 ± 0.009	0.412 ± 0.003	0.217 ± 0.003	0.395 ± 0.008
3822bF	BHBto4bF	0.784 ± 0.000	0.444 ± 0.011	0.975 ± 0.011	0.516 ± 0.002	0.287 ± 0.011	0.299 ± 0.001
3822bH*	BHBto4bH*	0.680 ± 0.000	0.328 ± 0.003	0.703 ± 0.007	0.468 ± 0.003	0.240 ± 0.001	0.305 ± 0.007
3823bF	BHBto5bF	0.760 ± 0.001	0.395 ± 0.001	0.943 ± 0.018	0.486 ± 0.007	0.296 ± 0.007	0.339 ± 0.001
3823bH*	BHBto5bH*	0.660 ± 0.003	0.312 ± 0.001	0.663 ± 0.015	0.425 ± 0.003	0.212 ± 0.001	0.334 ± 0.011
3728bF	EMR3Bto1bF	0.600 ± 0.002	0.232 ± 0.001	0.860 ± 0.000	0.226 ± 0.001	0.131 ± 0.004	0.657 ± 0.006
3728bH*	EMR3Bto1bH*	0.496 ± 0.002	0.143 ± 0.000	0.532 ± 0.015	0.179 ± 0.014	0.085 ± 0.001	0.540 ± 0.019
3729bF	EMR3Bto2bF	0.627 ± 0.002	0.239 ± 0.004	0.887 ± 0.014	0.252 ± 0.000	0.135 ± 0.005	0.625 ± 0.007
3729bH*	EMR3Bto2bH*	0.513 ± 0.007	0.152 ± 0.002	0.507 ± 0.003	0.185 ± 0.001	0.086 ± 0.008	0.493 ± 0.012
3730bF	EMR3Bto3bF	0.583 ± 0.002	0.235 ± 0.003	0.865 ± 0.008	0.225 ± 0.004	0.118 ± 0.001	0.687 ± 0.002
3730bH*	EMR3Bto3bH*	0.495 ± 0.002	0.142 ± 0.000	0.530 ± 0.003	0.157 ± 0.001	0.077 ± 0.004	0.554 ± 0.002
3820bF	EMR3Bto4bF	0.600 ±0.015	0.240 ± 0.018	0.82 ± 0.013	0.236 ± 0.011	0.143 ± 0.002	0.707 ±0.001

3820bH*	EMRBto4bH*	0.508 ± 0.003	0.148 ± 0.001	0.536 ± 0.008	0.170 ± 0.001	0.088 ± 0.005	0.498 ± 0.056
3821bF	EMRBto5bF	0.587 ± 0.005	0.240 ± 0.009	0.827 ± 0.013	0.222 ± 0.007	0.139 ± 0.009	0.630 ± 0.012
3821bH*	EMRBto5bH*	0.513 ± 0.004	0.146 ± 0.001	0.528 ± 0.049	0.168 ± 0.004	0.084 ± 0.006	0.437 ± 0.168
3746bF	Sh13.9Bto1bF	0.770 ± 0.006	0.372 ± 0.015	0.898 ± 0.004	0.496 ± 0.000	0.277 ± 0.005	0.345 ± 0.003
3746bH*	Sh13.9Bto1bH*	0.627 ± 0.002	0.262 ± 0.001	0.619 ± 0.016	0.392 ± 0.001	0.193 ± 0.003	0.343 ± 0.002
3747bF	Sh13.9Bto2bF	0.763 ± 0.006	0.341 ± 0.026	0.785 ± 0.094	0.492 ± 0.004	0.268 ± 0.010	0.383 ± 0.022
3747bH*	Sh13.9Bto2bH*	0.646 ± 0.001	0.270 ± 0.001	0.694 ± 0.001	0.406 ± 0.003	0.213 ± 0.002	0.359 ± 0.001
3748bF	Sh13.9Bto3bF	0.769 ± 0.003	0.365 ± 0.002	0.951 ± 0.009	0.487 ± 0.001	0.261 ± 0.003	0.315 ± 0.003
3748bH*	Sh13.9Bto3bH*	0.657 ± 0.001	0.269 ± 0.002	0.738 ± 0.006	0.402 ± 0.001	0.209 ± 0.002	0.309 ± 0.003
3831bF	Sh13.9Bto4bF	0.754 ± 0.011	0.349 ± 0.001	0.957 ± 0.010	0.490 ± 0.013	0.297 ± 0.001	0.337 ± 0.013
3831bH*	Sh13.9Bto4bH*	0.632 ± 0.004	0.258 ± 0.000	0.657 ± 0.004	0.389 ± 0.001	0.196 ± 0.003	0.352 ± 0.013
3132bF	MeSBto1bF	0.772 ± 0.004	0.243 ± 0.001	1.006 ± 0.007	0.485 ± 0.002	0.288 ± 0.001	0.343 ± 0.000
3132bH*	MeSBto1bH*	0.637 ± 0.003	0.243 ± 0.000	0.634 ± 0.025	0.373 ± 0.003	0.205 ± 0.008	0.331 ± 0.013
3101bF	EHTBto1bF	0.769 ± 0.005	0.266 ± 0.000	1.019 ± 0.003	0.472 ± 0.001	0.275 ± 0.001	0.346 ± 0.003
3101bH*	EHTBto1bH*	0.656 ± 0.001	0.241 ± 0.001	0.687 ± 0.009	0.389 ± 0.001	0.199 ± 0.004	0.402 ± 0.004
3102bF	EHTBto2bF	0.758 ± 0.002	0.228 ± 0.008	0.959 ± 0.019	0.476 ± 0.019	0.274 ± 0.005	0.330 ± 0.023
3102bH*	EHTBto2bH*	0.620	0.215	0.377	0.379	0.213	0.479
3103bF	EHTBto3bF	0.755 ± 0.002	0.265 ± 0.002	1.030 ± 0.003	0.471 ± 0.001	0.294 ± 0.001	0.328 ± 0.002
3103bH*	EHTBto3bH*	0.662 ± 0.001	0.242 ± 0.001	0.693 ± 0.002	0.394 ± 0.004	0.214 ± 0.000	0.313 ± 0.004
3734bF	EH9.2Bto1bF	0.751 ± 0.020	0.513 ± 0.037	0.904 ± 0.001	0.518 ± 0.000	0.307 ± 0.012	0.261 ± 0.008
3734bH*	EH9.2Bto1bH*	0.475 ± 0.002	0.174 ± 0.002	0.129 ± 0.001	0.340 ± 0.001	0.160 ± 0.004	0.752 ± 0.006
3735bF	EH9.2Bto2bF	0.741 ± 0.010	0.338 ± 0.010	0.901 ± 0.019	0.513 ± 0.001	0.271 ± 0.001	0.319 ± 0.004
3735bH*	EH9.2Bto2bH*	0.629 ± 0.000	0.253 ± 0.001	0.641 ± 0.019	0.406 ± 0.003	0.201 ± 0.002	0.306 ±0.000
3736bF	EH9.2Bto3bF	0.762 v 0.004	0.364 ± 0.003	0.936 ± 0.004	0.471 ± 0.002	0.259 ± 0.008	0.324 ± 0.003
3736bH*	EH9.2Bto3bH*	0.649 ± 0.002	0.272 ± 0.003	0.447 ± 0.002	0.391 ± 0.003	0.206 ± 0.004	0.411 ± 0.004
3824bF	EH9.2Bto4bF	0.745 ± 0.008	0.339 ± 0.002	0.840 ± 0.014	0.455 ±0.004	0.294 ± 0.017	0.329 ± 0.006
3824bH*	EH9.2Bto4bH*	0.638 ± 0.010	0.249 ± 0.008	0.565 ± 0.041	0.372 ± 0.007	0.181 ± 0.006	0.239 ± 0.121
3825bF	EH9.2Bto5bF	0.734 ±0.012	0.339 ± 0.002	0.915 ± 0.007	0.457 ± 0.003	0.271 ± 0.030	0.363 ± 0.003
3825bH*	EH9.2Bto5bH*	0.642 ± 0.001	0.250 ± 0.001	0.639 ± 0.030	0.384 ± 0.003	0.192 ± 0.003	0.332 ± 0.020

4916bF	EBBto1bF	0.719 ± 0.004	0.218 ± 0.002	0.982 ± 0.007	0.400 ± 0.006	0.227 ±0.001	0.441 ± 0.006
4916bH*	EBBto1bH*	0.621 ± 0.000	0.194 ± 0.001	0.720 ± 0.002	0.318 ± 0.001	0.164 ± 0.007	0.433 ± 0.001
4917bF	EBBto2bF	0.731 ± 0.003	0.264 ± 0.018	0.984 ± 0.022	0.398 ± 0.006	0.243 ± 0.009	0.377 ± 0.004
4917bH*	EBBto2bH*	0.641 ± 0.001	0.226 ± 0.003	0.701 ± 0.004	0.332 ± 0.02	0.176 ± 0.001	0.364 ± 0.003
4918bF	EBBto3bF	0.732 ± 0.001	0.271 ± 0.009	0.998 ± 0.029	0.434 ± 0.004	0.247 ± 0.004	0.423 ± 0.004
4918bH*	EBBto3bH*	0.654 ± 0.03	0.250 ± 0.006	0.752 ± 0.006	0.371 ± 0.003	0.195 ± 0.000	0.424 ± 0.003

Table 5: Amino acid data for *Bithynia tentaculata* opercula measured during the MVPP and presented in the paper. Data from Shoeburyness were previously presented in Roe et al. (2011). Error terms represent one standard deviation about the mean for the duplicate analyses for an individual sample. Each sample was bleached (b), with the free amino acid fraction signified by 'F' and the total hydrolysable fraction by 'H*

Section / test pit / borehole	Location within section (see Table 3)	Field code	Labo-ratory code	Field moi-sture (%)	K conc. (%)	Th conc. (%o)	U conc. (%o)	Over-burden thick-ness (m)	Cosmic dose rate (Gy/ka)	Total dose rate (Gy/ka)	Mean recycling ratio	Mean thermal transfer (%)	Mean D_e (Gy)	Age estimate (ka)	Age range (ka)	MIS attrib-ution
Southend peninsula																
Barling Gravel Pit (?Barling Gravel)																
S1	Top	BLNG05-01	X2447	5.0	0.6±0.03	2.0±0.1	0.6±0.03	1.7	0.17±0.02	0.98±0.05	1.05	2.25	172.3±28.0	176.1 ± 30.2	206-146	7a-6
S1	Middle	BLNG05-03	X2449	13.0	1.2±0.06	3.4±0.17	0.8±0.04	2.3	0.16±0.01	1.50±0.11	1.00	1.95	206.8±19.0	137.8 ± 16.0	154-122	6-5e
S1	Base	BLNG05-05	X2451	6.0	0.8±0.04	1.3±0.07	0.4±0.02	4.7	0.12±0.01	1.01±0.06	1.01	2.39	125.5±17.1	124.4 ± 18.7	143-106	6-5d
Doggetts Farm (Rochford Gravel)																
TP2	Middle	DOGF05-02[255]	X2466	12.0	0.2±0.01	1.1±0.06	0.3±0.02	1.7	0.17±0.03	0.46±0.04	1.03	1.79	125.2±18.3	374.8 ± 46.0	321-229	9-7d
TP3	Top	DOGF05-03	X2467	9.0	0.4±0.02	2.9±0.15	0.6±0.03	1.0	0.19±0.02	0.84±0.04	0.98	1.99	216.6±8.8	257.4 ± 12.8	270-245	8-7e
Apton Hall Farm (Rochford Channel Gravel)																
(BH1	*Top of sands*	*APHF05-01*	*X3080*	*10.1*	*0.6±0.03*	*1.8±0.09*	*0.6±0.03*	*8.7*	*0.08±0.01*	*0.82±0.06*	*0.98*	*1.04*	*359.0±21.1*	*435.3 ± 40.2*	*475-395*	*12-11)*
Dengie peninsula																
Burnham Wick Farm (?Dammer Wick Gravel)																
(TP1	*Base*	*BURN05-01[125]*	*X2455*	*17.0*	*1.4±0.07*	*4.6±0.23*	*1.1±0.06*	*1.6*	*0.17±0.02*	*1.74±0.12*	*0.97*	*1.54*	*203.3±29.4*	*116.6 ± 18.8*	*135-98*	*5e-5c)*
TP2	Middle	BURN05-03	X2457	8.0	0.4±0.02	2.3±0.12	0.4±0.02	1.0	0.18±0.02	0.76±0.04	1.04	1.44	141.7±18.8	186.6 ± 26.6	213-160	7c-6
Mersea Island																
Cudmore Grove (Cudmore Grove Gravel)																
S1	Near base	CG05-01	X2459	5.0	0.3±0.02	1.8±0.09	0.3±0.02	4.0	0.13±0.01	0.59±0.03	-	-	165.8±14.9	282.7 ± 29.0	312-254	9-8
S1	Near base (replicate)	CG05-02	X2460	5.0	0.2±0.01	1.9±0.10	0.4±0.02	4.0	0.13±0.02	0.52±0.03	1.01	1.01	152.2±7.1	290.3 ± 21.4	312-269	9-8
S2	Top	CG05-03	X2461	5.0	0.27±0.01	3.7±0.19	1.0±0.05	3.2	0.14±0.02	0.85±0.04	1.02	1.16	270.5±48.0	318.8 ± 58.8	378-260	11-8
(S2	*Base*	*CG05-05*	*X2463*	*7.0*	*0.31±0.02*	*2.9±0.15*	*0.6±0.03*	*3.9*	*0.13±0.01*	*0.72±0.03*	*0.99*	*0.83*	*150.5±11.6*	*209.4 ± 18.9*	*228-190*	*7d-6)*

Table 6: OSL dosimetry, equivalent dose and age estimates for samples from Medway deposits in eastern Essex. Most samples were 180-255 μm grain size, samples superscripted[125] were 125-180 μm grain size and those superscripted[255] 255-355 μm grain size. Gy = Grays, ka = thousands of years. Dose rate estimate based on neutron activation analysis (NAA). Age calculated by dividing mean De by total dose rate. Error quoted as one standard error (standard deviation / √n). MIS boundaries are taken from Shackleton *et al.* (1990) and Bassinot *et al.* (1994). Sample X3080 is not listed in Schwenninger et al. (2007) or Wenban-Smith et al. (2007a). All other samples have been recalculated for presentation in this paper. Samples in italics and brackets are less reliable – see text for full details.

Sediment body	OSL or AAR data (see Tables 5 and 6, Figures 2 and 4)	Suggested MIS attribution
Southend peninsula		
?Barling Gravel	BLNG05-01 (X2447), BLNG05-03 (X2449), BLNG05-05 (X2451) – 206-106 ka	?7a – 5d
Rochford Gravel	DOGF05-02 (X2466), DOGF05-03 (X2467) – 321-229 ka	9 – 7d
Rochford Clay	5 *Bithynia tentaculata* opercula from APHF 05 <3A> (NEaar 3737-3739, 3826-3827)	
Shoeburyness Clay	4 *Bithynia tentaculata* opercula from Borehole S1, 13.9 m (NEaar 3746-3748, 3831) 1 operculum from S1, 14.42-14.44 m (NEaar 3132)	9
Barling Channel interglacial deposits	Penkman et al. (2008b, in press)	
Rochford Channel Gravel	OSL unreliable	>9
Shoeburyness Channel Gravel	-	-
Southend Channel	No clear evidence for deposits	-
Southchurch Gravel	-	10
Dengie Peninsula		
?Dammer Wick Gravel	BURN05-03 (X2457) – 213-160 ka	?7c-6
East Wick Channel deposits	AAR from TQ99NE/45A 12.2-13.7 m	9
Burnham Clay	-	?9
Burnham Channel Gravel	-	–
Asheldham Upper Gravel	-	10
Tillingham Clay	3 *Bithynia tentaculata* opercula from Borehole EH1, 7.55 m (NEaar 3101-3103) 5 from EH1, 9.2 m (NEaar 3734-3736, 3824-2835)	11
	5 *Bithynia tentaculata* opercula from Bradwell Hall <bulk 13> (NEaar 3731-3733, 3822-2823);	11
Tillingham Channel Gravel	-	12 – 11
Asheldham Lower Gravel	-	12
Mersea Island		
East Mersea Restaurant Site	5 *Bithynia tentaculata* opercula from East Mersea Restaurant Site, Sample 3 (NEaar 3728-3730, 3820-3821)	5e
Cudmore Grove Gravel	CG05-01 (X2459), CG05-02 (X2460), CG05-03 (X2461) – 378-254 ka	8 (OSL 11-8)
Cudmore Grove Channel interglacial deposits	(several *Bithynia tentaculata* opercula – Roe et al., 2009)	9
Cudmore Grove Channel Gravel	-	10 – 9
Mersea Island Gravel	-	12 or 10

Table 7. Suggested ages for deposits from the Southend Peninsula, Dengie Peninsula and Mersea Island - youngest deposits at the top. MVPP Field Interventions, more reliable OSL dates (see Table 6 and text) and suggested MIS attributions are shown and discussed further in the text. Stratigraphic nomenclature after Roe and Preece (in press, Table 2). MIS boundaries are taken from Shackleton et al. (1990) and Bassinot et al. (1994).

Figure 1. Map showing detailed mapping of eastern Essex undertaken by Bridgland (1983a,b; 1988), location of key sites referred to in the text and the cross-sections in Figures 6, 7 and 9. Estuarine channel fills are shown after BGS mapping of sheets 258/259 and Roe et al. (2009) for Cudmore Grove and Bridgland et al. (1999) for Clacton.

Figure 2. Hydrolysed Ala D/L value plotted against Free Ala D/L value in *Bithynia tentaculata* opercula from the Medway Valley Palaeolithic Project, along with data from Clacton (Penkman et al., 2010) and Cudmore Grove (Roe et al., 2009). Error bars for the individual sites represent one standard deviation about the mean for the replicate analyses, to show only the central tendency of the results for clarity. The cross hairs representing the range of data observed in UK sites correlated with MIS 5e-11 are two standard deviations to show the full spread of this data from multiple sites (Penkman et al., 2008b, in press).

Figure 3. Plots showing inter-aliquot variability in the SAR De values from the OSL samples. Means and standard deviations shown are the arithmetic mean based on all 6 aliquots, except for CG05-03 (X2461) where disc 8 was much greater than the values from the other discs (see 3k) and the mean was based only on the other 5 aliquots.

Figure 4. Summary diagram showing OSL and AAR age estimates from the region in relation to the marine isotope stratigraphy, after Shackleton et al. (1990) and Bassinot et al. (1994).

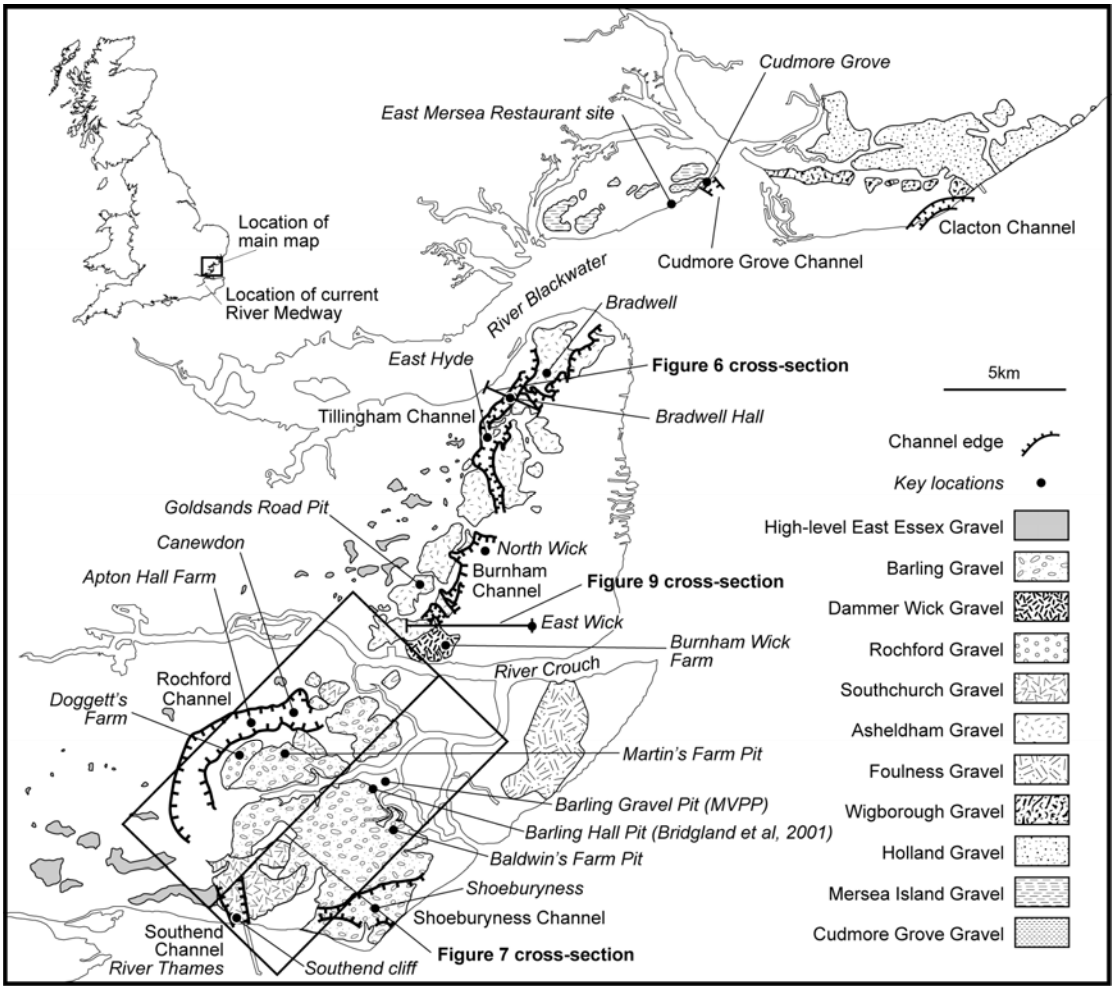
Figure 5. Stratigraphic context of and photographs from thin section sample SS05(3). The photographs show a macroscopic view of the whole sample plus: a) close-up view of ice lensing fabric in lower unit; b) close-up view of geliflucted aggregates in lower unit; c) close-up view of geliflucted clay skins in lower unit; d) close-up view of clay coatings on aggregates in upper unit.

Figure 6. West to east section across the Tillingham Channel at Bradwell Hall. The location of this cross-section is shown on Figure 1. Boreholes shown are from the British Geological Survey (prefixed TL), MVPP test pits and PhD thesis investigations by David Bridgland (DRB-CFMPT-1 = Curry Farm Pit).

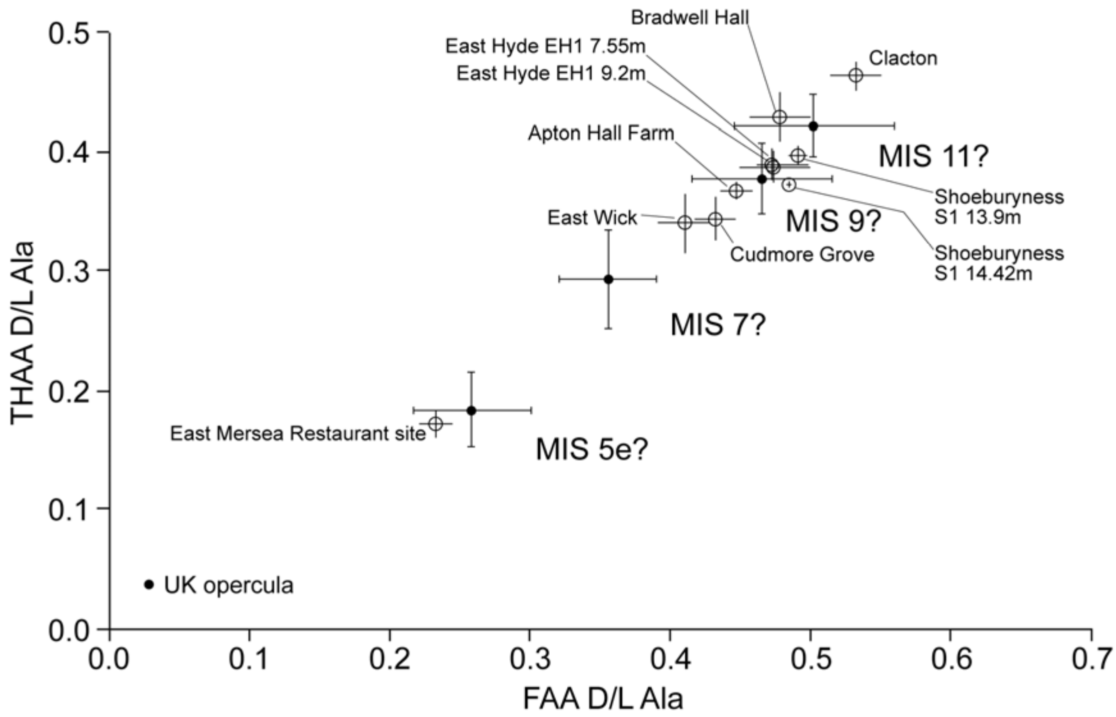
Figure 7. South-west to north-east long profile of Pleistocene deposits in the western part of study region EX1, from Southend to Rochford. The location of this cross-section is shown on Figure 1. Boreholes shown are from the British Geological Survey (prefixed TQ) and MVPP test pits (various prefixes relating to local site names, some of which yielded dating samples and are listed in Table 3).

Figure 8. Sections indicating salinity characteristics and biostratigraphical zonation of the eastern Essex channel fills, after Roe (1999). Zonation is based upon the interglacial zonation scheme proposed by Turner and West (1968).

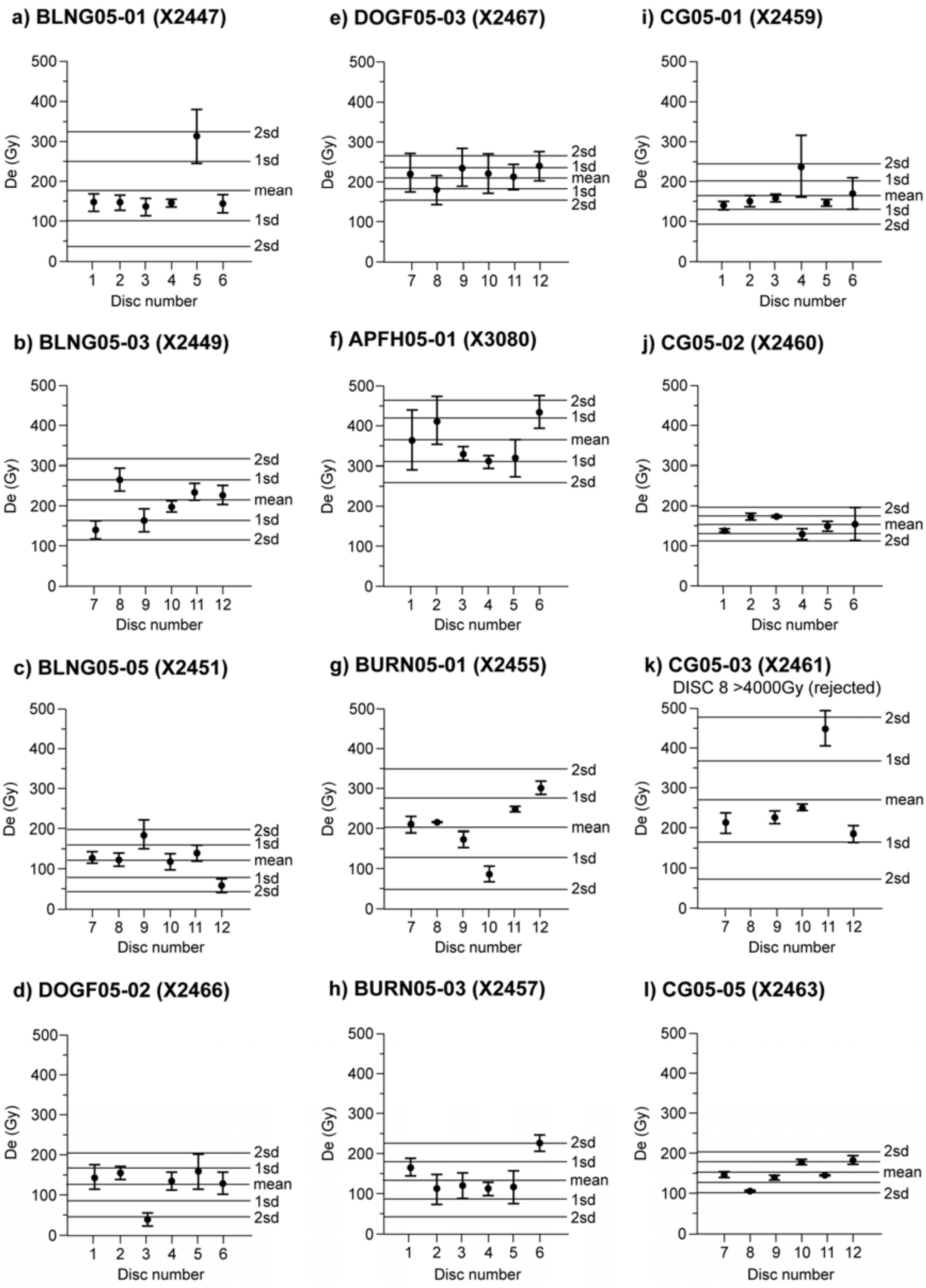
Figure 9. West to east section across the Burnham Channel to the north of Burnham-on-Crouch. The location of this cross-section is shown on Figure 1. Borehole data were accessed from the British Geological Survey.

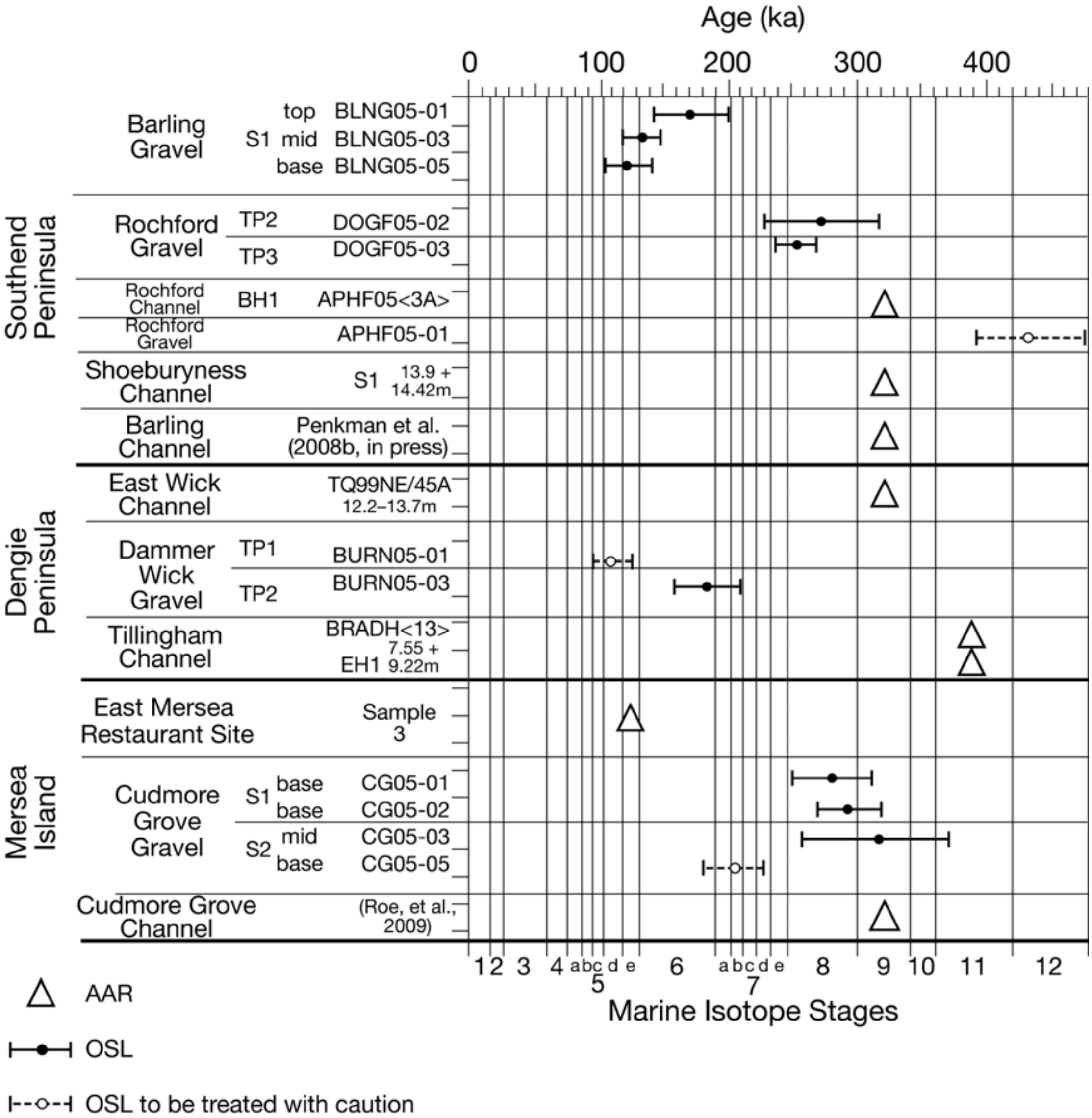


Cudmore Grove
East Mersea Restaurant site
Location of main map
Location of current River Medway
Clacton Channel
Cudmore Grove Channel
River Blackwater
Bradwell
East Hyde
Figure 6 cross-section
5km
Tillingham Channel
Bradwell Hall
Channel edge
Key locations
Goldsands Road Pit
High-level East Essex Gravel
Canewdon
North Wick
Burnham Channel
Apton Hall Farm
Figure 9 cross-section
Barling Gravel
Dammer Wick Gravel
East Wick
Burnham Wick Farm
Rochford Gravel
Rochford Channel
River Crouch
Doggett's Farm
Southchurch Gravel
Asheldham Gravel
Martin's Farm Pit
Foulness Gravel
Barling Gravel Pit (MVPP)
Wigborough Gravel
Barling Hall Pit (Bridgland et al, 2001)
Baldwin's Farm Pit
Holland Gravel
Mersea Island Gravel
Shoeburyness
Shoeburyness Channel
Cudmore Grove Gravel
Southend Channel
Figure 7 cross-section
River Thames
Southend cliff

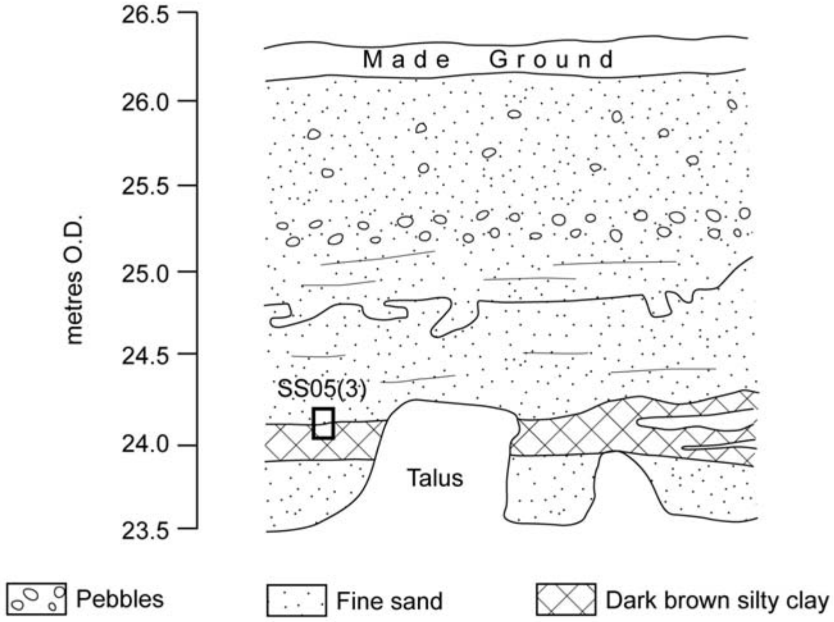


Bradwell Hall
East Hyde EH1 7.55m
East Hyde EH1 9.2m
Clacton
Apton Hall Farm
MIS 11?
Shoeburyness
S1 13.9m
East Wick
MIS 9?
Cudmore Grove
Shoeburyness
S1 14.42m
MIS 7?
East Mersea Restaurant site
MIS 5e?
UK opercula
THAA D/L Ala
FAA D/L Ala
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

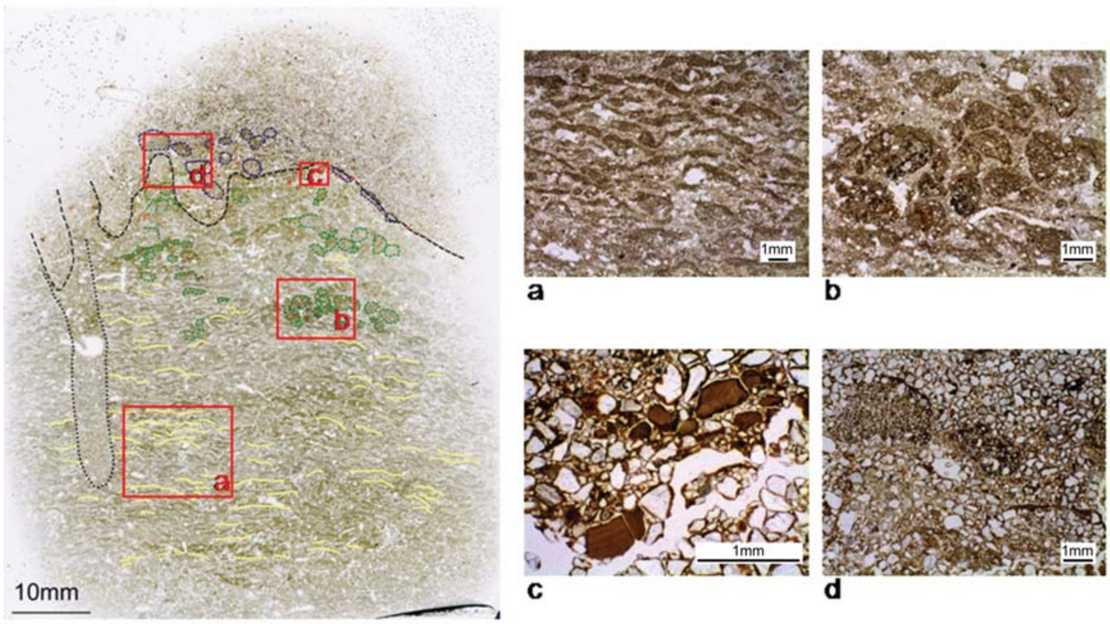

a) BLNG05-01 (X2447)
e) DOGF05-03 (X2467)
i) CG05-01 (X2459)
b) BLNG05-03 (X2449)
f) APFH05-01 (X3080)
j) CG05-02 (X2460)
c) BLNG05-05 (X2451)
g) BURN05-01 (X2455)
k) CG05-03 (X2461)
DISC 8 >4000Gy (rejected)
d) DOGF05-02 (X2466)
h) BURN05-03 (X2457)
l) CG05-05 (X2463)
De (Gy)
Disc number
2sd
1sd
mean



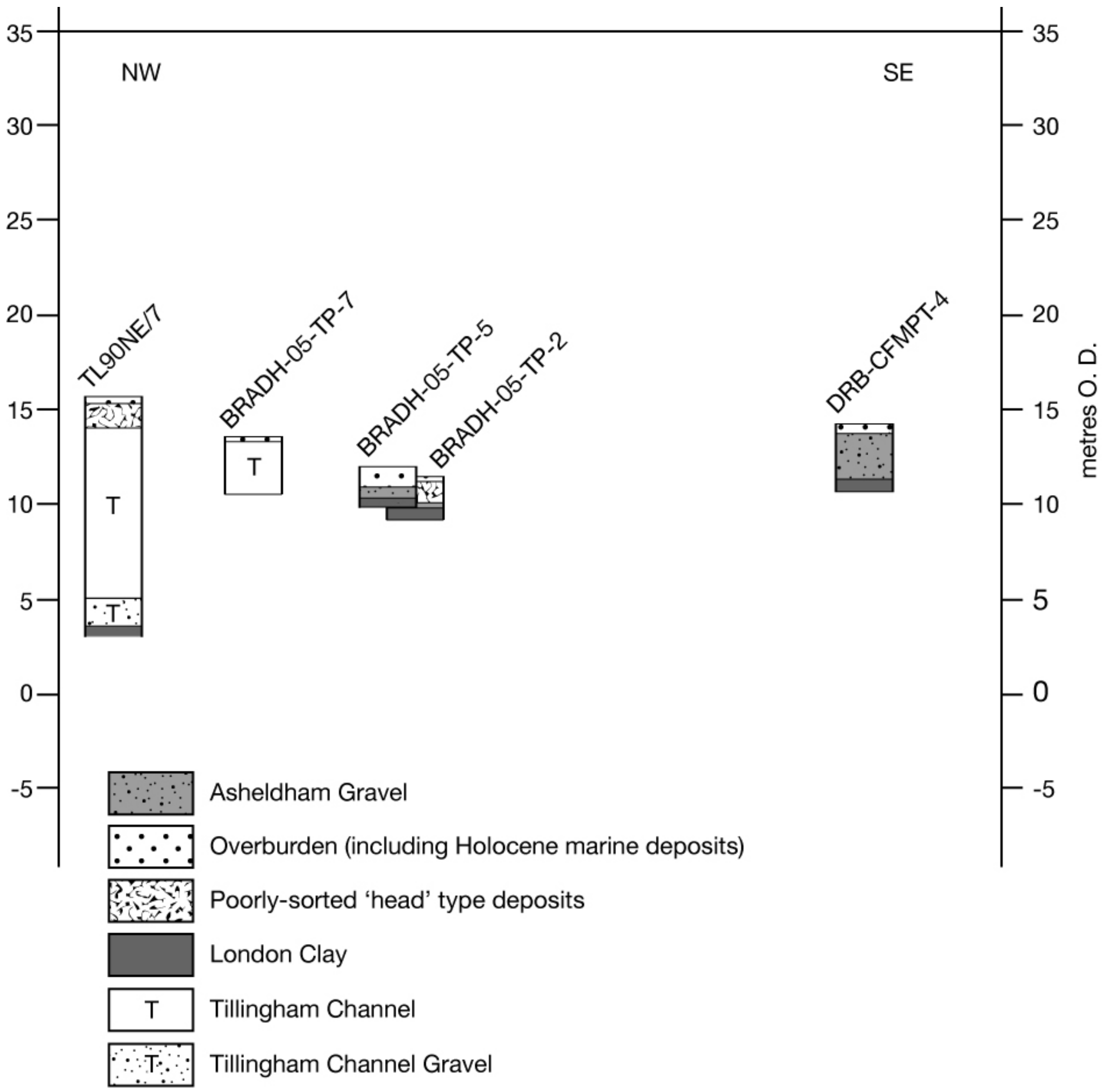
Age (ka)
0
100
200
300
400
Barling Gravel
S1
top BLNG05-01
mid BLNG05-03
base BLNG05-05
Southend Peninsula
Rochford Gravel
TP2 DOGF05-02
TP3 DOGF05-03
Rochford Channel
BH1 APHF05<3A>
Rochford Gravel
APHF05-01
Shoeburyness Channel
S1 13.9 + 14.42m
Barling Channel
Penkman et al. (2008b, in press)
Dengie Peninsula
East Wick Channel
TQ99NE/45A 12.2–13.7m
Dammer Wick Gravel
TP1 BURN05-01
TP2 BURN05-03
Tillingham Channel
BRADH<13>
EH1 7.55 + 9.22m
Mersea Island
East Mersea Restaurant Site
Sample 3
Cudmore Grove Gravel
S1 base CG05-01
base CG05-02
S2 mid CG05-03
base CG05-05
Cudmore Grove Channel
(Roe, et al., 2009)
1 2 3 4 a b c d e 6 a b c d e 8 9 10 11 12
5
7
Marine Isotope Stages
AAR
OSL
OSL to be treated with caution



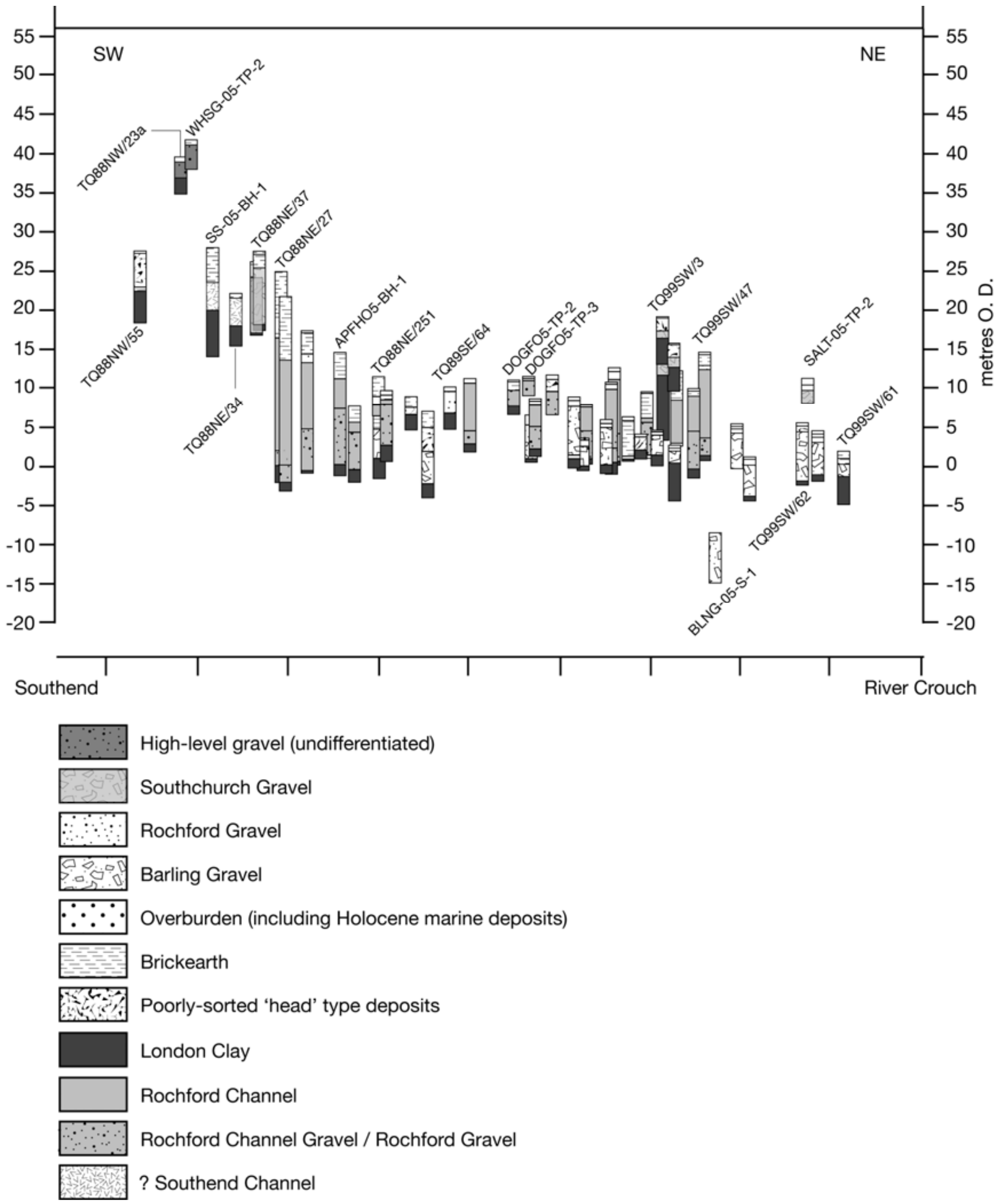
Made Ground
metres O.D.
26.5
26.0
25.5
25.0
24.5
24.0
23.5
SS05(3)
Talus
Pebbles
Fine sand
Dark brown silty clay

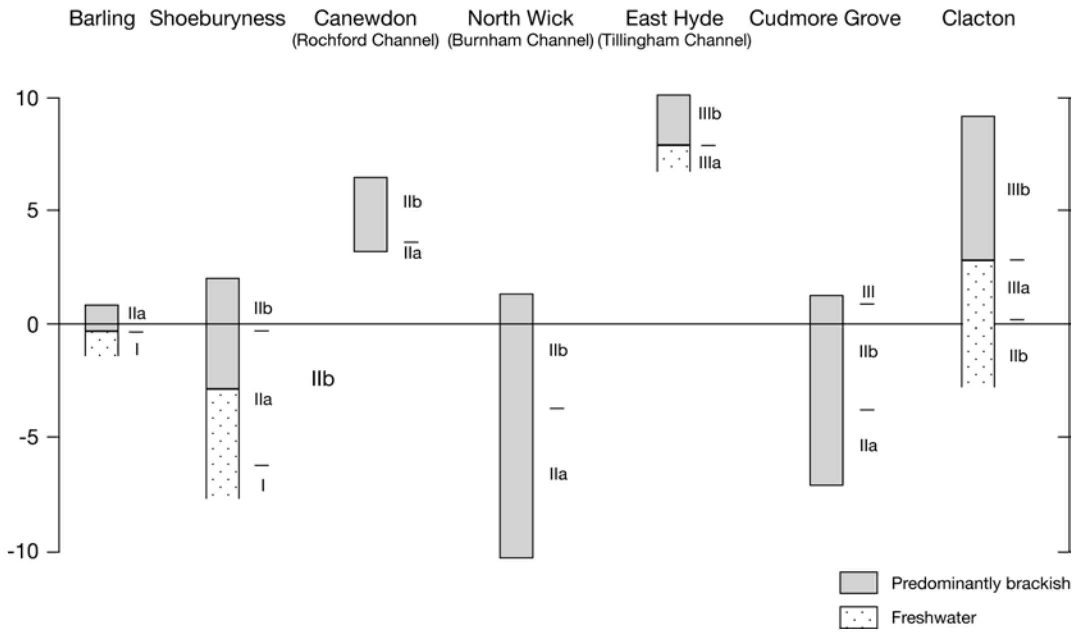


a
b
c
d
10mm
1mm

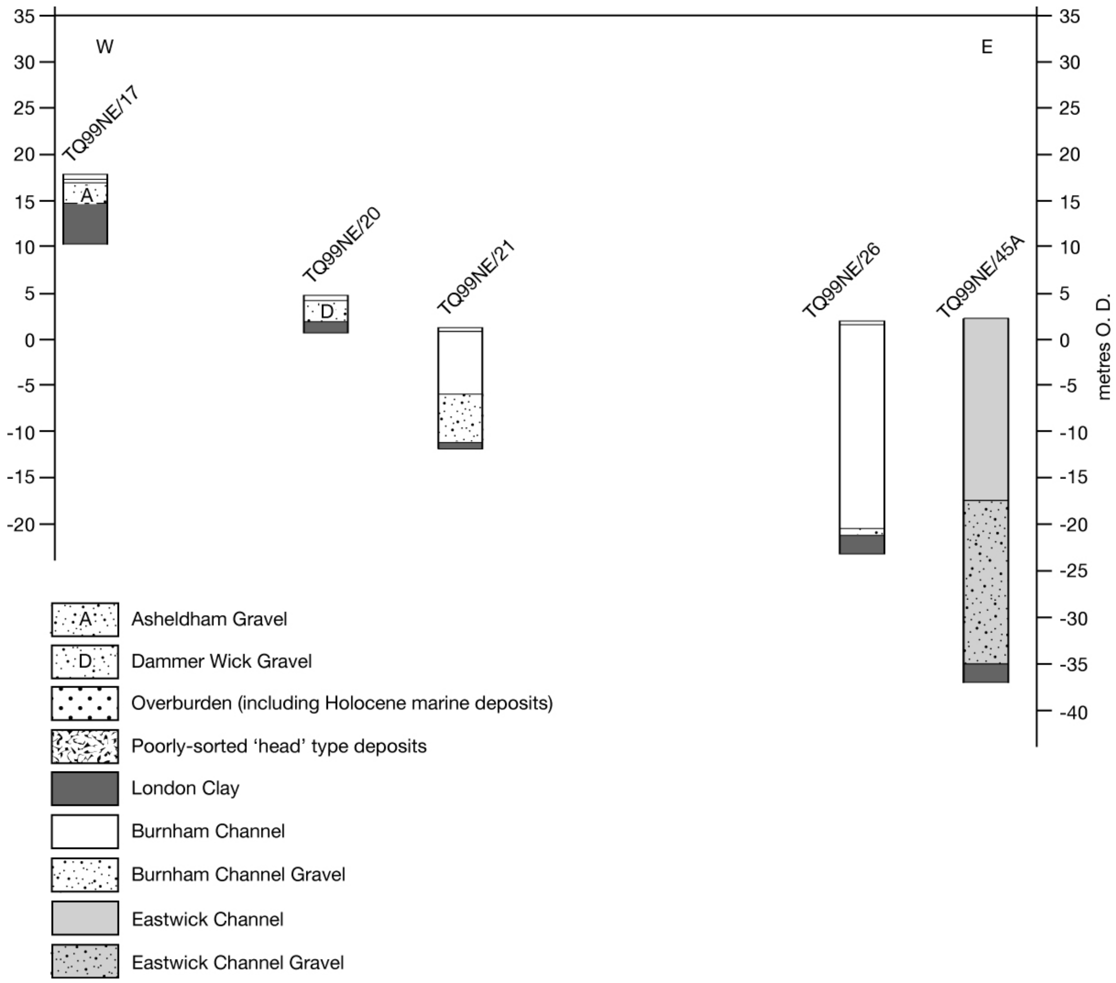


35
30
25
20
15
10
5
0
-5
NW
SE
metres O. D.
TL90NE/7
BRADH-05-TP-7
BRADH-05-TP-5
BRADH-05-TP-2
DRB-CFMPT-4
T
Asheldham Gravel
Overburden (including Holocene marine deposits)
Poorly-sorted 'head' type deposits
London Clay
Tillingham Channel
Tillingham Channel Gravel


SW
NE
metres O. D.
TQ88NW/23a
WHSG-05-TP-2
TQ88NW/55
SS-05-BH-1
TQ88NE/37
TQ88NE/27
TQ88NE/34
APFHO5-BH-1
TQ88NE/251
TQ89SE/64
DOGFO5-TP-2
DOGFO5-TP-3
TQ99SW/3
TQ99SW/47
SALT-05-TP-2
TQ99SW/61
TQ99SW/62
BLNG-05-S-1
Southend
River Crouch
High-level gravel (undifferentiated)
Southchurch Gravel
Rochford Gravel
Barling Gravel
Overburden (including Holocene marine deposits)
Brickearth
Poorly-sorted 'head' type deposits
London Clay
Rochford Channel
Rochford Channel Gravel / Rochford Gravel
? Southend Channel



Barling
Shoeburyness
Canewdon
(Rochford Channel)
North Wick
(Burnham Channel)
East Hyde
(Tillingham Channel)
Cudmore Grove
Clacton
10
5
0
-5
-10
IIa
I
IIb
IIa
I
IIb
IIb
IIa
IIb
IIa
IIIb
IIIa
III
IIb
IIa
IIIb
IIIa
IIb
Predominantly brackish
Freshwater



35
30
25
20
15
10
5
0
-5
-10
-15
-20
W
E
TQ99NE/17
A
TQ99NE/20
D
TQ99NE/21
TQ99NE/26
TQ99NE/45A
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
metres O. D.
A
Asheldham Gravel
D
Dammer Wick Gravel
Overburden (including Holocene marine deposits)
Poorly-sorted 'head' type deposits
London Clay
Burnham Channel
Burnham Channel Gravel
Eastwick Channel
Eastwick Channel Gravel